SOCIO-ECONOMICS OF BIOSECURITY:
FOUR ESSAYS ON BIOINVASIONS
AND GENETICALLY MODIFIED AGRICULTURE

PhD Thesis

Rosa Binimelis i Adell

Supervision: Dr. Joan Martínez Alier
Dr. Roger Strand

Submission data: November 2008

Autonomous University of Barcelona
PhD Program in Environmental Sciences

icta Institute of Environmental Science and Technology • UAB

SOCIO-ECONOMICS OF BIOSECURITY:
FOUR ESSAYS ON BIOINVASIONS
AND GENETICALLY MODIFIED AGRICULTURE

Abstract

The doctoral thesis "Socio-economics of biosecurity: Four essays on bioinvasions and genetically modified agriculture" deals with two highly controversial processes –the introduction of invasive species (IS) and genetically modified organisms (GMOs)-, under the umbrella of the concept of biosecurity. Biosecurity refers to a strategic and integrated approach that encompasses the policy and regulatory frameworks that analyse and manage risks in food safety, animal life and health, and plant life and health, including associated environmental risk. It covers the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and management of invasive alien species and genotypes.

In spite of the aspiration to an integrated approach, socio-economics aspects of biosecurity have been much less studied than the technical ones. This is due in part to the modern model of science, that establishes a clear distinction between risk assessment, which is meant to be purely scientific and independent of value-judgements and to provide a supposedly objective basis for decisions based on "sound-science" (usually considering only those health and environmental impacts); and risk management, which supplements the former with social and political considerations. Moreover the societal concerns which cannot be individualised and quantified, or which challenge the economic model, are excluded. This economic model is rooted in a liberal approach based on the idea that, essentially, the legislation should ensure the freedom and right of individuals (displayed in the free market). This is done by means of dumping decisions to the individual sphere, and by setting self interested free choice as the only way of safeguarding rights and liberties.

The consequences of this approach are analysed through four published (or accepted) articles dealing with four case studies from an empirical point of view. The first article analyses two invasive processes: zebra mussel (*Dreissena polymorpha*) in the Ebro River (Spain) and *Hydrilla verticillata* in Lake Izabal (Guatemala). The second one describes the debate and implications of GM maize cultivation in Catalonia and Aragon (Spain) on the European coexistence legislation between GM and non-GM crops. Complementing it, a third article deepens the analysis of the same conflict, by using the DPSIR framework and focusing on the stakeholders narratives. A fourth article, merges processes of invasive species and GMOs by analysing the driving forces, consequences and responses to the emergence of a glyphosate-resistant weed after the massive diffusion of GM glyphosate-resistant soy in Argentina. The four cases are analysed from a qualitative perspective, based on field work and participatory methods. An awareness of the allocation of power is also common to the four case studies, which are analyzed through the perspective of conflict that characterizes political ecology.

Key words

Argentina, biosafety, biosecurity, coexistence with GMOs, *Dreisssena polymorpha,* genetically modified maize, Guatemala, *Hydrilla verticillata*, socio-economics of bioinvasions, *Sorghum halepense,* Spain

Resum en català

La tesis doctoral "Socio-economics of biosecurity: Four essays on bioinvasions and genetically modified agriculture" (*Socio-economia de la bioseguretat: Quatre assaigs sobre bioinvasions i l'agricultura modificada genèticament)* analitza dos processos altament controvertits –la introducció d'espècies invasores i d'organismes modificats genèticament (OMG)-, sota el concepte paraigua de la bioseguretat. Bioseguretat far referència a un enfocament estratègic i integrat que reuneix els marcs polítics i reguladors per analitzar i gestionar riscos en les àrees de la seguretat alimentària i la vida i sanitat animal i vegetal, incloent el risc ambiental associat. El concepte cobreix la introducció de plagues de plantes, plagues i malalties d'animals i zoonosis, la introducció i alliberament d'organismes modificats genèticament i els seus productes i la introducció i la gestió d'espècies i genotips exòtics invasors.

A pesar de la voluntat de tenir un enfocament integrat, els aspectes socio-econòmics de la bioseguretat han estat molt menys estudiats que aquells aspectes tècnics. En part això és degut al model científic modern, que estableix una clara distinció entre l'avaluació del risc, que és purament científica i independent dels judicis de valors, i que té per finalitat proveir de bases objectives per a prendre les decisions basades en criteris "estrictament científics" (normalment només considerant impactes de salut i ambientals); i la gestió de risc, que complementa el procés anterior amb consideracions socials i polítiques. A més a més, aquelles preocupacions socials que no poden ser individualitzades i quantificades, o que qüestionen el model econòmic, són excloses. Aquesta aproximació, de fonaments liberals, està basada en la idea de que, essencialment, la legislació ha d'assegurar la llibertat i el dret dels individus (expressats a través de lliure mercat). Per fer-ho, les decisions són traspassades a l'esfera individual, establint-ho com l'única manera de garantir aquests drets.

Les conseqüències d'aquesta visió són examinades a través de quatre articles publicats (o acceptats) que analitzen quatre casos d'estudi des d'un punt de vista empíric. El primer article estudia dos processos d'invasions biològiques: el del musclo zebrat (*Dreissena polymorpha*) al riu Ebre i el de l'*Hydrilla verticillata* al llac Izabal (Guatemala). El segon descriu el debat i les implicacions del conreu de blat de moro modificat genèticament a Catalunya i Aragó per la legislació europea sobre coexistència entre conreus MG i aquells que no ho són. Complementant-lo, un tercer article aprofundeix en el mateix conflicte usant el marc DPSIR per estructurar la informació i centrant-se en les narratives dels actors implicats. Finalment, el quart article convergeix els dos processos (espècies invasores i transgènics) en analitzar les causes, conseqüències i respostes a l'aparició d'una "mala

herba” resistent al glifosat després de la difusió massiva del conreu de soja resistent al glifosat a Argentina. Els quatre casos són estudiats des d’una perspectiva qualitativa, basada en treball de camp i mètodes participatius. La perspectiva d’anàlisis del poder és també comú als quatre casos, que són investigats des del marc de l’estudi de conflictes que caracteritza l’ecologia política.

Paraules clau

Argentina, bioseguretat, blat de moro modificat genèticament, coexistència amb organismes modificats genèticament (OMG), *Dreissena polymorpha,* Estat espanyol, Guatemala, *Hydrilla verticillata*, socio-economia de les bioinvasions, *Sorghum halepense*

Table of contents

Introduction

The doctoral thesis "Socio-economics of Biosecurity: Four essays on bioinvasions and genetically modified agriculture" includes four articles and an introductory chapter. This introduction contains a brief discussion on the main issues developed in the thesis, a review of the methodology, a summary of the main findings for each article and conclusions and some final remarks. It applies the unifying concept of *biosecurity* to the different case studies.

This thesis deals with two highly controversial processes –the introduction of invasive species (IS) and genetically modified organisms (GMOs)-, which challenge public policy under the umbrella of the concepts of biosecurity and biosafety. Both processes, although having some substantial differences (i.e. the introduction of GMOs are willed processes while bioinvasions are events rather than acts) present also commonalities. In fact, GMOs have been discussed for the last 20 years in light of bioinvasions (Ewel et al., 1999; Hancock, 2003; Parker and Kareiva, 1996; Williamson, 1993; 1994). Both question conventional views on science and environmental ethics and how nature is understood while confronting different rationales, competing goals and development models.

The socio-economic aspects of biosecurity

The concept of biosecurity has gained importance at the international policy arena during the last years, to become a main crossover between biodiversity, agriculture and environmental conservation. The term was firstly used in the United States to describe an approach aiming to prevent or decrease the transmission of infectious diseases in crops and livestock, and also for referring to the defence against biological weapons (e.g. the deliberate introduction of smallpox or anthrax in human populations). However, more recently the term has been applied more broadly to cover efforts to prevent harm from both intentional and unintentional introductions of organisms to human health, infrastructure and the environment, as well as to the agricultural crop and livestock industries (McNeely al. 2001, Meyerson and Reaser 2002; Waage and Mumford, 2008). It was first introduced into legislation in 1993 in Australia, when the Biosecurity Act was approved (Jay and Morad, 2006). Although its meaning shifts with the implementation or geographical context (Sunshine Project, 2003; Waage and Mumford, 2008), a frequently used definition is the one established by FAO (2003):

> "*Biosecurity* refers to a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risks in the sectors of food safety, animal life and health, and plant life and health, including associated environmental risk. *Biosecurity* covers the introduction of plant pests, animal pests and diseases, and zoonoses[1], the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and management of invasive alien species and genotypes. *Biosecurity* is a holistic concept of direct relevance to the sustainability of agriculture, food safety, and the protection of the environment, including biodiversity".

By contrast, the term biosafety[2] has a more limited scope. It refers to the introduction, release and use of genetically modified organisms. The Cartagena Protocol on Biosafety applies it to "the transboundary movements, transit, handling and use of all living modified organisms that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health" (CPB, 2000).

Biosecurity and biosafety cannot be separated from the social context where both invasive species and GMOs are introduced and established (Kleinman and Kinchy, 2007; Kropiwnicka, 2003; Jay and Morad, 2006). At the same time, as it will be discussed in this dissertation, the management of invasive species and GMOs is characterised by uncertain outcomes, multiple and conflicting objectives among the many interested parties with different views on both facts and values.

Invasion processes are considered a human-induced phenomenon. In that sense, socio-economic arrangements can foster or restrict the introduction of invasive species (Dalmazzone, 2000; Kowarik, 2003) or create the conditions for alien species to flourish or fail (Jay and Morad, 2006). This human involvement comprises not only the configuration of driving forces, the different ways in which invasive species impacts are perceived by the different social groups (Binimelis et al., 2007; Levine et al., 2003; Stokes et al., 2006), and the implementation of responses (McNeely et al., 2001; Norgaard, 2007), but also the very conception of the invasive process as an environmental and socioeconomic problem (Jay and Morad, 2006; Larson, 2007a; 2007b; Lodge and Schrader-Frechette, 2003; Shrader-Frechette, 2001). Take for instance the issue of eradicating hedgehops in the Outer

[1] Zoonose is any infectious disease that is able to be transmitted (by a vector) from other animals, both wild and domestic, to humans or from humans to animals.

[2] Both biosafety and biosecurity terms are translated at Spanish and Catalan as *bioseguridad* and *bioseguretat* respectively.

Hebridean Island, Scotland, as described by Coates (2003). An islander introduced some individuals in order to clear his garden of slugs and snails in the mid 1970s. Rapidly, hedgehops proliferated at expenses of the island's avifauna. In 2003, when the British Government's conservation body for Scotland discussed the eradication of hedgehogs, the British Hedgehog Preservation Society was up in arms. It initiated a campaign in order to avoid the culling[3]; and even several children wrote wanting to adopt a hedgehog. Finally, after four years of intense debate it was decided to translocate the animals to the mainland. Other examples are described in Hall (2003) or Jay and Morad (2006).

Similarly, genetic engineering, as any other technology, cannot be separated from the industrial and research complex in which it has been developed (Kloppenburg, 1988; Lyson, 2002; McAfee, 2003), the social context in which it is adopted and disseminated (Daño, 2007; McAfee, 2008) and the institutional setting of application (McAfee, 2003). In this sense, McAfee (2008) explains how the controversy about genetic "contamination" of indigenous maize varieties in Mexico by GM maize from the United States has been intensified by rising Mexican discontent with the terms of the bilateral trade agreement between the two countries. The assessment of its consequences is also subject to social discussion as the different spheres of society –economic, political, social, cultural or ethical-foster and are all affected by the these processes, through with differing intensity and unequal distribution.

Following this, Daño (2007) summarizes the need for assessing the potential socio-economic impacts of GMOs in four general aspects, which will, at least in part, overlap with the consequences of the deliberate introduction of invasive species: a) social responsibility of the scientist who develop and the decision-makers who introduce a technology into a society in order to bear for the potential consequences once the technology is released into the environment; b) inter-generational-responsibility in order to ensure that adverse effects are avoided (due to the long-term characteristics of the environmental and socio-economic impacts); c) social acceptance, which means that stakeholders and society in general are involved in the decision-making; and d) the need for measures for reducing long-term cost, specially when dealing with potential irreversible damages.

The socio-economic research on biosecurity

[3] See Uist Hedgehog Rescue (UHR) webpage: http://www.uhr.org.uk/

In this thesis the introduction of invasive species and GMOs are seen as issues in the governance of biosecurity. However, the socio-economic analysis of these processes has received so far less attention in the literature than the biological and technological aspects.

Biological invasions have been present in human history for many years (Crosby, 1986) and they have been object of ecological research for a few decades, focusing either on the invasiveness of the species or the invasibility of the ecosystems (Kolar and Lodge, 2001; Pyŝek et al., 2004; Shine et al., 2000; Williamson, 1996). Research has also focused on the effects of invasive species on ecosystems and their functioning, and on the damages to the services the ecosystems provide (Binimelis et al., 2007; Levine et al., 2003). By contrast, the study of the socio-economic aspects of biological invasions is more recent (Jay and Morad, 2006; Larson, 2007b; Robbins, 2004). The centre of attention has been the economic costs caused by invasive species or their management (Barbier, 2001; Horan et al., 2002; Perrings et al., 2002; 2005; Pimentel et al., 2000; 2001; 2005).

Despite the popularity of such monetary evaluations, these aggregate quantitative economic analyses are designed to estimate (actual or fictitious[4]) market impacts, rather than those outside the economic sphere. For these reasons, these studies have been accused of not constituting a solid platform for the development of a biosecurity policy (Waage et al., 2005). Only a minority of studies use more holistic approaches, which could complement the limited available economic data of biological invasions impacts, allow the use of qualitative data (e.g. esthetical or ethical values) and make uncertainty explicit. Following this reasoning, deliberative approaches are recommended (Born et al., 2005), although their practical implementation has been limited (Cook and Proctor, 2007; Evans et al., 2008; Monterroso, 2005; Rodríguez-Labajos, 2006).

Another area of socio-economic examination has been the analysis of the driving forces and pathways fostering the invasive species introduction. Most of these analyses are done by means of statistical correlates (see e.g. Hulme et al., 2008; Vilà and Pujadas, 2001), usually lacking a sound explanatory power. In that sense, Vilà and Pujadas (2001) find a significant contribution of the Human Development Index for explaining the variation in density of alien plants. However, it is not clear how this index, composed by measures of life expectancy, literacy, educational level and the gross domestic product per capita contributes to the introduction and spread of these species. A minority go further by shifting the focal point from the species to the socio-economic system that fosters the invasion process, as "it is not species but socio-biological networks that are invasive" (Robbins, 2004; see also Bright, 1999). The same reasoning can be found from a historical approach,

[4] By fictitious market impact I refer to valuations in terms of willingness to pay and the like.

as the pioneering work by Crosby (1986) and Melville (1994) shows (see also Jay and Morad, 2006).

In a similar way, GMOs introduction has been vastly discussed in the scientific literature, mainly from a technical perspective. Leaving aside the literature in the field of molecular biology, research on biosecurity –or biosafety- of GMOs has mostly addressed environmental (Barratt et al., 2006; Snow et al., 2004; Tiedje et al., 1989; Wolfenbarger and Phifer, 2000) and health aspects (British Medical Association, 2004; Pryme and Lembcke, 2003)[5], often leaving aside the integration of socio-economic and ethical considerations (Daño, 2007). In that sense, decisions on biosafety issues are characterised by giving a central role to biotechnology expertise, in contrast to other areas such as ecology or sociology (Funtowicz and Strand, 2007). As it will be seen, this low incorporation of socio-economic research is reflected in failures in actual decision-making processes (Fransen et al., 2005).

Socio-economic enquiry on GMOs has focused on the economic aspects and the social distribution of costs and benefits derived from the introduction of biotechnology. Some of the literature is rooted in a positive view of the benefits of industrial farming, assuming a scale neutrality of the technology and the necessity to engage with global markets (e.g. European Commission, 2002; Herring, 2008). By contrast, other authors present a much more critical perspective on the benefits of such model, arguing that it will contribute to inequity favouring certain groups among others (Buttel et al., 1985; Duffy, 2001; Kloppenburg, 1988). Linked to this second view, authors have warned on the consequences of the private ownership and marked-based management of biotechnology through patents and the trade-related intellectual property rights (TRIPS) agreement (McAfee, 2003), in line with the main arguments of international mobilisation against GMOs (Scoones, 2008; see e.g. Via Campesina, GRAIN, ETCGroup, Third World Network).

Research has also been conducted on the compatibility of GM crops with other type of agriculture, at a technical (Altieri, 2005; Müller, 2003; Ponti, 2005) or at the conceptual level, arguing for a clash of rationales in relation to the agriculture model, the global trade rules or corporate control and property rights (Levidow and Boschert, 2007; Lyson, 2002; Verhoog, 2007; see also the second article of this thesis). Related to these concerns, a branch of literature coming from the science and technology studies has focused on the

[5] In spite of it, an article in *Science* announced: “Health Risks of GM Foods: Many Opinions but Few Data” (Domingo, 2000). The same view was expressed by the British Medical Association (2004) and Traavik and Heinemann (2007) reporting a lack of answers to some of the most pervasive questions related to the issue. Health issues are not dealt with in this thesis.

failure of the science-based assessment procedures to incorporate societal concerns (Carr and Levidow, 2000; Sarewitz, 2004), and the lack of social legitimacy of the regulations (Levidow and Marris, 2001). It is linked with the lack of integration of ethical issues in the management of biosecurity. At this respect, several authors have warned that these aspects are discussed at a technical level by professional bioethicists but non as an integrated cross-cutting topic, hindering a more sensible and socially robust evaluation (Devos et al., 2008; Carr and Levidow, 2000; Funtowicz and Strand, 2007; Wynne, 2001). Finally, an important area of socio-economic research has been the study of public perceptions on the biotechnology, as in the Eurobarometer surveys (Gaskell et al., 2003) or among different stakeholders' groups (Kondoh and Jussame, 2006; Marris et al., 2001; Wu, 2004).

In a similar way, the relation between GMOs and invasive species has also been discussed in the scientific literature from a technical point of view. On the one hand, different authors have argued that GMOs be included under the category of non-native species (Ewel et al., 1999), while others have focused on whether GMOs are likely to be more competitive than native species, enhancing their invasibility potential (Parker and Kareiva, 1996). On the other hand, some studies have claimed that self-dispersing GMOs could be advantageous when released purposely to the environment in order to address problems in public health, invasive species or pest control (for a review, see Angulo and Gilna (2008)). In that sense, for instance, Spanish researchers have developed and tried a transmissible vaccinating GM myxoma virus to protect threatened native Spanish rabbits while the same virus was used traditionally and in GMO research as a biocontrol against rabbits in Australia (Angulo and Gilna, 2008). Finally, other studies warned on the pressure selection resulting from the increased consumption of glyphosate in herbicide-resistant GM crops, leading to the emergence of herbicide-resistant weeds (Altieri, 2005; Barton and Dracup, 2000; Ervin et al., 2003; Martinez-Ghersa et al., 2003; McAfee, 2003; Powles, 2003; Snow et al., 2004; Steinbrecher, 2001).

Scientific neutrality and objectivity are central to the lack of socio-economic engagement in the scientific literature on bioinvasions and GMOs. In the case of invasive species, there has been an intense debate in the literature concerning the very definition of the concept[6]. On the one hand, from a biogeographical perspective, a distinction between native and alien species has been established, based on spatial and temporal distribution patterns (Pyšek et al., 2004; Richardson et al., 2000; Williamson, 1996). From this viewpoint,

[6] Early versions of the following classification have been used by the UAB-ALARM team (Rodriguez-Labajos, Monterroso and Binimelis), e.g. in Monterroso et al. (2005) and Walter and Binimelis (unpublished).

impacts should be excluded from the definition of invasive species as “defining invaders as those species with the largest impacts is an exercise in subjectivity that will be unlikely to contribute to clarity” (Pyšek et al., 2004; see also Daehler (2001)). On the other hand, from an impact-based perspective, the definition is led by policy-making objectives that emphasize mitigation of negative impacts on biological diversity and/or human welfare (Davis and Thompson, 2000; 2001; IUCN, 2000; McNeely et al., 2001; Shine et al., 2000). This approach was used by the Convention of Biological Diversity for defining invasive species as: ‘‘alien species that threaten ecosystems, habitats or species with economic or environmental harm” (CBD, 2002). Finally, a third perspective considers the concept of alien invasive species as a social construction inspired by nativism, a discriminative ideology based on personal or cultural values (Theodoropoulos, 2003).

The differences in approach will determine which biosecurity actions are to be taken and which are the targeted species, if any. On the one hand, the first definition is claimed to be value-free, as an invader can be easily measured by analyzing population growth and distance of spread from origin (Daehler, 2001). However, it is still context dependent because the notion of alien implies the delimitation of temporal and spatial boundaries (Davis and Thompson, 2000). Moreover, some degree of arbitrariness is inherent in the idea of “overabundant” introduced species (Shrader-Frechette, 2001). The biogeographical perspective also entails the notion that all introduced species are, per se, less desirable than natives (Simberloff, 2003). A historical approach to biological invasions reveals changes in subjective perceptions (Alderman, 2004; Arcioni, 2004; Beinart and Middleton, 2004; Beinart , 2008; Crosby, 1986; Pimentel et al., 2001) and while some species can be firstly judged as beneficial and prejudicial afterwards, others can result in conflicting outcomes (Binimelis et al., 2007; de Wit et al., 2001; Quist and Hubert, 2004; Shafroth et al., 2006;).

Furthermore, the first and the second perspectives entail a science model based on the separation between facts and values in which scientists provide pure information and others make decisions based on it (Funtowicz and Strand, 2007; Larson, 2007a). However, facts do not stand for themselves, but are negotiated through particular frames of reference (Cassey et al*.,* 2005). Moreover, perception of costs and benefits of biological invasions, and responses to them, usually differ among groups of stakeholders (Norgaard, 2007; Stokes et al., 2006). It is through a negotiation process among organizations, experts, policy makers and the civil society that biological invasions embrace different meanings and are treated through particular frameworks, resulting in a specific local approach to the issue. As Lodge and Schrader-Frechette (2003) point out: “any characterisation that any of all non-indigenous species are good or bad is a value judgment, not science (…) The unavoidability of such valued judgement also reveals why development of policy for invasive species should depend much more than in scientific expertise" (see also Larson, 2007a). As the first article ("A social analysis of bioinvasions of *D.polymorpha* in Spain and *H.verticillata* in Guatemala") and the fourth article ("'Transgenic Treadmill': Responses to the emergence and spread of the Glyphosate-Resistant Johnsongrass in Argentina") of this thesis show, the very definition of invasive species must be considered relative and strongly influenced by culture and politics (Robbins, 2004).

In a parallel way, the separation of facts and values is also advocated in the discussion on the normative framework for GMOs introduction. Take for instance the negotiation of the Cartagena Protocol on Biosafety (CPB). It was negotiated under the Convention on Biological Diversity to regulate the cross-border movement of the products of modern biotechnology[7]. Article 26 of the CPB allows countries to take intro account socio-economic considerations, in a consistent manner with existing international obligations by which countries must be bond[8]. As stated by Mackenzie et al. (2003), the question of including socio-economic considerations in the text was one of the major controversial issues between mostly developing and developed countries during the CPB negotiations. While most developing countries pushed for the including socio-economic considerations as one of the bases for conducting the risk assessment and managing and making decisions on GMO imports, most developed countries argued that socio-economic aspects are issues of national domestic concern, subjective and difficult to quantify for making decisions and that therefore, such considerations should be excluded of the CPB (see Kleinman and Kinchy (2007) and Stabinsky (2000) for a discussion on the inclusion of socio-economic aspects in the CPB). Finally, this section was only accepted provided that its application was consistent with existing international obligations, especially trade rules. In spite of it, there is no agreement on which type of considerations should be taken; neither how should it be

[7] Modern biotechnology is described in the Cartagena Protocol of Biosafety as the application of "in vitro nucleic acid techniques, including recombinant deoxyribonucleic acid (rDNA) and direct injection of nucleic acid into cells or organelles; or fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers and that are not techniques used in traditional breeding and selection" (CBD, 2000). The most commonly used techniques are the utilisation of the bacterium *Agrobacterium tumefaciens*, which is naturally able to transfer DNA to plants, and the 'gene gun', which shoots microscopic particles coated with DNA into the plant cell. Modern biotechnology can therefore introduce a greater diversity of genes into organisms than traditional methods of breeding and selection.

[8] Besides, countries may also incorporate other socio-economic impacts than those explicitly include in article 26 in their domestic legislation on biosafety (Mackenkie et al., 2003).

done and under which liability regime[9]. For this reason, Veit Köster (2001), who was chair of the Biosafety Working Group, complained that "socio-economic considerations are broadly speaking not legitimate under the World Trade Organisation rules, the aim of which is more or less to get rid of such considerations". Examples of such socio-economic considerations are the analysis of income security and distribution derived from the introduction of GMOs, the effect on rural labour or on gender issues (Third World Network, 2008; see also Fransen et al., 2005).

The same reasoning operates regarding the coexistence regulation. As the second article of this thesis shows ("Coexistence of plants, coexistence of farmers. Is an individual choice possible?"), the technical coexistence framework in Europe between transgenic and "organic" agriculture is constrained within the quantifiable economic aspects derived from the admixture of GM and non-GM crops. Other socio-economic extra-market goods or "bads" (e.g. loss of trust among consumers, admixture of GMOs with local varieties, increase of farmer's dependency on external inputs), are excluded as they cannot be objectively quantified or are incommensurable.

Risk assessment vs risk management of biosecurity

These normative premises are based on what Funtowicz and Strand (2007) call the modern model. It is based in the simple assumption that the relation between science and policy flows one-way: science informs policy by producing objective, valid and reliable knowledge. Truth speaks to power. As a result, developing a policy is a matter of becoming informed by science and, in a second step, of allocating the diverse values and interests. Science becomes then a primary source of legitimacy for policy decision. In this way, risk policy is divided in two stages: the risk assessment, which is meant to be purely scientific and independent of value-judgements, provides a supposedly objective basis for decisions; and the risk management, which supplements the former by social and political considerations.

However, as this thesis shows the conflicts around GMOs and IS (invasive species) are not just a clash between "sound science" and "unsound" knowledge claims. In practice, different experts and stakeholders provide competing representations of risks due to methodological uncertainty (e.g. see discussion on isolation distances for GM maize), different disciplinary approaches (Kvakkestad et al., 2007) or value-based political or

[9] This was one of the main issues at the 4th Conference of the Parties (COP) held in Bonn in May 2008. However, the only agreement was to gather more information in order to take up again the negotiations in the 6th COP in year 2012.

ethical positions (Sarewitz, 2004). At the same time, stakeholders contribute with different sort of valuable knowledge and weigh differently ecological, economic, ethical or aesthetic values, all of them representing legitimate views and interests but usually overlooked, as these concerns fall outside the “risk window”, which only makes visible that which has been predefined as a relevant risk (Jensen et al., 2003). Furthermore, both processes of GMOs introduction and the dissemination of IS have the potential for unexpected and surprising effects in which “we do not know what we do not know”. We are then facing complex problems, characterised by confrontation at the societal level, but also by low consensus on the scientific issues and the analytical methods to be applied, in which decision stakes are high and multiple narratives exist depending on complex and value-laden considerations, shaped by interests in different cultural, ethical and socio-economic contexts. “Sound science” is then necessary, but not a sufficient condition for the robust assessment of biosecurity.

The present risk policy establishes that a GMO should be approved, or an IS allowed to be introduced, if the risk of adverse effects on human health and the environment is acceptably small (which is in itself a value-judgement). The exclusion of other type of societal concerns is rooted in the neoliberal approach (Kleinman and Kinchy, 2007), focusing on the idea that, essentially, the legislation should ensure the freedom and right of individuals (Jensen et al., 2003), displayed in the free market. This is done by means of dumping decisions to the individual sphere (Cocklin et al., 2008; Devos, 2008), and by setting self interested free choice as the only way of safeguarding rights and liberties (Roff, 2008). Given the appropriate legal norms, damage caused by a technology will be compensated for through liability cases – this is the economic approach. In fact, as shown in this thesis, the compensation of (often uncertain) damage through the enforcement of liability is not at all straightforward.

As a consequence of the dominance of the economic approach, the frame excludes other rationales and criteria, such as food quality, farmer independency or trust in public regulatory institutions, which cannot be easily individualised and quantified, challenging the economic model in which these processes are embedded in favour of the discussion of technical solutions. At the same time, the same logic of individualisation applies to the responses to these processes, which favours reactive measures that favour those with the resources to adapt while transfers the risk to society and the environment (Perrings, 2005).

At first sight, the articles in this thesis deal with disparate topics; bioinvasions and GM agriculture may be thought to be quite different subject matters. The case study on Argentina provides a clear link between one bioinvasion and GM agriculture because the use of glyphosate in genetic modified soybean cultivation has produced resistance in an invasive species, *Sorghum halepense*. The details and the uncertainties of this case are analyzed in article 4. More importantly, however, at a deeper level the problems of governance of biosecurity (and biosafety) bring the research in this thesis together.

Another common thread is the methodology used in my research, based on field work and participatory methods. An awareness of the allocation of power is also common to the different case studies, which are analyzed through the perspective of conflict that characterizes political ecology. Although bioinvasions might be considered at first sight as a threat to which all sectors of society should be opposed, we show that this is not the case or rather that society divides on the urgency of the threat and the policies to be adopted. How to compare between differently distributed social and geographical impacts? How to balance environmental vs economic impacts or the present vs the future generations? How is liability defined? Still more importantly, who has the power to frame the issues and determine policy, and who is entitled to define the levels of risk and uncertainty (or ignorance) socially tolerated?

Objectives

The main objectives of this thesis are:

- To study the intertwined scientific, political, economic and social contexts in the governance of biosecurity;
- To explore the common and differing aspects of bioinvasions and GM agriculture;
- To discuss the social relevance of uncertainty beyond the customary approach of quantifiable risks;
- To investigate through case studies the different valuation of costs of benefits of threats to biosecurity, depending on social structures and power distribution.

Methodological approach

This thesis aims to study the socio-economics of biosecurity starting from an empirical approach. For this purpose, four case studies have been analysed: the invasion processes of the zebra mussel (*Dreissena polymorpha)* in the Ebro River (Spain) and *Hydrilla verticillata* in Lake Izabal (Guatemala), the emergence of a glyphosate-resistant biotype of johnsongrass (*Sorghum halepense*) in Argentina, and the introduction and dissemination of GM maize in Catalonia and Aragon (Spain).

The empirical cases are characterised by complexity inherent to the invasion or introduction processes, lack of complete data (which does not always allow analysing their impacts from a quantitative perspective) and the existence of conflicting perspectives regarding their significance, which requires an interdisciplinary perspective to explore them. Research has focused on the analysis of how different stakeholders frame the studied problems. In order to draw out these different frames, a discourse analysis approach has been used. This approach has been widely used for analyzing environmental conflicts in general (Hajer, 1995) but also for controversies over biotechnology (Heller, 2002, 2006; Kleinman and Kinchy, 2007; Levidow and Boschert, 2007; Levidow and Carr, 2007) and invasive species (Larson et al., 2005; Norgaard, 2007). Discourse is here defined as a way to understand a shared system of knowledge or belief and the social practices in which it is produced through which meaning is given to the world (Hajer, 1995, p. 44).

The stakeholders' practices and experiences are highlighted, not only focusing on their world as "thought" but also "lived". For doing so, qualitative field research methods were used, aiming to elicit actors' perceptions and understanding of the processes, as well as their practices (Kvale, 1996). These techniques included semi-structured group and individual in-depth interviews and also participant observation. Semi-structured interviews start from an interview guide that includes main thematic points, but it is open in order to be flexible for including topics not initially foreseen by the interviewer. The informants were selected among principals experts and actors who participate in the debate (at a conceptual or practical level, e.g. farmers), based on their different roles on the issue, so as to explore their various perceptions.

Most interviews were audio or video recorded and literally transcribed. The rest was registered with field notes, as the informants did not wish to be audio recorded. The great majority of participants were interviewed in their workplace of house, aiming to contextualise the research activities while providing a comfortable environment for those participating in the interviews. In order to analyse the transcripts, interviews and field notes were coded. In one of the cases the collected information was analyzed using ATLAS.ti, a qualitative data analysis software which allows to analyse large data sets through setting categories, systematise and refine concepts (Kelle, 2000; Lewins and Silver, 2007).

The interviews for the *Hydrilla verticillata* case in Guatemala were performed by Iliana Monterroso, while for the other cases, they were performed by myself with the collaboration of the respective co-authors. The analysis of the interviews was conducted co-operatively in the first paper; while it was done by me in the rest of the papers constituting this thesis.

A detailed description of the methodology used in each case study (e.g. the structure of semi-structured interviews for each case study, or the specific targeted stakeholders) is given in the methodological section of each paper.

A note on authorship

The thesis is constituted by an introduction and four articles published in peer-review scientific journals, all of them dealing with different aspects of the socio-economics of biosecurity. It is a product of the European project ALARM. The author has worked in close collaboration with Iliana Monterroso and Beatriz Rodriguez Labajos over four years, as well as with other members of the socio-economic team in ALARM. We have worked together on some case studies, but also separately on other cases. Some articles or book chapters that we have published together with them or other co-authors, or that are accepted for publication, are not included in this thesis. These include:

- Monterroso, I., Binimelis, R., Rodríguez-Labajos (in press). New methods for the analysis of invasion processes: Multi-criteria evaluation of the invasion of *Hydrilla verticillata* in Lake Izabal, Guatemala. Journal of Environmental Management.
- Rodríguez-Labajos, B., Binimelis, R., Monterroso, I., (in press). Multi-level driving forces of biological invasions. Ecological Economics.
- Rodríguez-Labajos, B., Binimelis, R., Cardona, C., Dittmer, K., Martínez-Alier, J., Monterroso, I., Munnè, A., (in press). Chronicle of a bioinvasion foretold: distribution and management of the zebra mussel (*Dreissena polymorpha*) invasion in Spain. In Settele, J., (ed.). ATLAS of Biodiversity, Pensoft.
- Binimelis, R., Strand, R. (2008). Spain and the European Debate on GM Moratoria vs Coexistence. In Funtowicz, S., Guimeraes Pereira, A.. (eds), Science for Policy: New Challenges, New Opportunities. Oxford University Press, Delhi, pp 110-122.
- Rodríguez-Labajos, B., Binimelis, R., Martínez-Alier, J., Munnè, A., 2008. Reciente pero rápida invasión del mejillón cebra en los ríos españoles. In Vilà, M., Valladares, F., Traveset, A., Santamaría, L., Castro, P. (eds.), Invasiones Biológicas, serie Ciencia y Divulgación, CSIC.
- Binimelis, R., Born, W., Monterroso, I., Rodríguez-Labajos, B., 2007. Socio-economic impact and assessment of biological invasions. In Nentwig, W., (ed), Biological Invasions. Ecological Studies, 193. Springer-Verlag, Berlin-Heidelberg, pp. 331-347.

Moreover, we have presented our work in several international and national conferences and workshops.

The first article of this thesis, dealing with the analysis of two invasive processes in Spain and Guatemala has been published in *Environmental Management* (2007) co-auhored with Iliana Monterroso and Beatriz Rodríguez Labajos. The second article, published in the *Journal of Agricultural and Environmental Ethics* (2008) describes the debate and implications on the European coexistence legislation between GM and non-GM crops. Complementing it, a third article deepens the analysis of the same conflict by using the DPSIR framework and focusing on the stakeholders narratives. It has been accepted for publication in *Ecological Economics* (2008). It is co-authored with Iliana Monterroso and Beatriz Rodríguez Labajos. A fourth article, accepted for publication in *Geoforum* (2008), merges processes of invasive species and GMOs by analysing the driving forces, consequences and responses of the emergence of a glyphosate-resistant weed after the massive diffusion of GM glyphosate-resistant soy in Argentina. This article is co-authored with Walter Pengue and Iliana Monterroso.

Summary and main conclusions of the articles

Article 1: A social analysis of the bioinvasions of *Dreissena polymorpha* in Spain and *Hydrilla verticillata* in Guatemala

Biological invasions are conceptualised under different definitions in the literature. This paper examines different stakeholders' positions in bioinvasion processes by comparing two cases occurred in aquatic ecosystems: the invasion process of *Dreissena polymorpha* in the Ebro River (Spain) and the case of *Hydrilla verticillata* in Lake Izabal (Guatemala). This analysis allows discussing the implications of the different conceptions of the phenomenon at the management level.

This is done by first introducing the issue of biological invasions, analysing the different definitions and conceptions used in the literature for referring to them. Then, the two cases are characterised, describing both the analysed species and the socio-economic and environmental characteristics of the host ecosystem, which explain establishment and could favour further spread. An analysis of the main stakeholders concerned with the biosecurity management around the species is presented, by describing their involvement as drivers, as affected actors (showing e.g. how they value the multidimensional impacts) and promoters or detractors of the proposed management strategies.

The discussion focuses on the relevance of incorporating the different stakeholders' interests and values in the analysis and management of biological invasions. In that sense, the configuration of the phenomenon of invasive species as an environmental issue depends on the stakeholders' views on drivers, impacts and responses. Thus, so as to effectively address invasion processes, it is important to take into account stakeholders' interests and values. This entails bringing into the decision-making process the perspectives of stakeholders by consultation and exchange of information. In this sense, participatory methodologies are a tool for improving the knowledge of the problem. Participation also influences the legitimacy of decisions around the management options.

However, in both cases (in Spain and Guatemala) the initial approach by the authorities was a technical one, reducing the boundaries of the management scenario to a decision regarding the most effective control option in monetary terms. Consensus of future management scenarios for ecosystems is not pursued; instead, technical measures to manage invasion species would be implemented, with a low level of agreement between the different stakeholders, unable to fit their own economic and social interests and values to the sustainability of aquatic ecosystems under this approach.

In that sense, although social analysis of stakeholders' positions is necessary in order to foster management actions, it also reveals conflicts on the relevant criteria, the boundaries of the system and on the very definition of invasive species.

Article 2: Coexistence of plants and coexistence of farmers: Is an individual choice possible?

The debate on coexistence between GM crops and conventional and "organic" agriculture was first introduced in 2002 by the European Commission aiming to deal with the emerging concerns derived from the admixture between GM, conventional, and organic crops. This issue was very relevant for organic producers, who are committed to a worldwide consensus not to use GMOs. At the same time, the coexistence framework intended to lift the existing ''de-facto'' moratorium within the European Union on GM commercial agriculture leaving the market to operate freely. This policy framework was seen a compromise solution, intending to reduce the conflicts on GMOs by the establishment of science-based technical measures to ensure coexistence (such as the 0.9% admixture level allowed).

Previous studies were conducted ex-ante based on modelling and experimental cases, due to the lack of commercial fields in most European countries. The objective of this paper is to revise the concept of coexistence as a policy frame that avoids conflicts by allowing the free market to operate by analysing the situation in Catalonia and Aragon, where 23,000 and 35,900 ha of GM maize were sown in 2007 respectively. This research involved qualitative techniques by means of group and individual in-depth interviews and participant observation.

The analysis revealed a social confrontation between proponents and opponents of GM technology. In that sense, without an agreement of the objectives to be achieved, the technocratic coexistence policy framework leads to a legitimacy crisis. There are thus confronting ideas on the feasibility to establish isolation distances or segregate the product and regulate liability in case of admixture, responding to contrasting world-views.

The study analyses also the difficulties that “organic” farmers face in practice in order to claim compensation if “contamination” takes place, due to technical uncertainties (e.g. for measuring the level of “contamination” or its origin) and because of social constraints. Individually affected “organic” farmers suing for compensation would be obliged to identify the farmer responsible for the contamination, leading to local confrontation in small villages. Moreover, beyond economic compensation, there are issues of the general model to be adopted by agriculture in a society aware of environmental concerns. As a result, the area devoted to organic maize has been reduced significantly since the first analysis for the detection of GM traces were conducted. Framing the problem as a technical issue has resulted not in coexistence but in the promotion of GM agriculture over organic agriculture.

Article 3: Catalan agriculture and genetically modified organisms (GMOs) – An application of DPSIR model

This paper starts from the same case study analysed in the previous paper to focus on the stakeholders’ positions on how GMOs governance influences the state of the environment in Catalonia. For doing so, the potential of the DPSIR (Driving forces – Pressures – State – Impact – Responses) methodology as a communication tool that structures information about the interactions between society and the environment is analysed. The paper first examines the advantages and shortcomings of the DPSIR model, as well as how it has been used in the context of GMOs and organic agriculture. Then, the next section characterises the Catalan maize sector and the current state of the GMOs crops and organic farming. Stakeholders’ positions were analysed through secondary sources and field research, which included qualitative techniques such as workshops, group and individual in-depth interviews as well as participant observation. Information from the case study was organised according to the DPSIR model categories.

The case study shows that this model is ambiguous when used as an analytical tool in value-laden complex situations, where multiple perspectives and definitions exist. In that sense, current definitions of the DPSIR framework establish the need for a scientific causal proof of the relationship between pressures and impacts, relying on a strong realistic view of knowledge. Stakeholders agree in describing the state of the agro-environment in Catalonia as being in crisis although their positions differ regarding the role played by GMOs. GM agriculture is seen by a group of actors as a pressure on the agro-environment, while for others it represents a modernising response not only to an economic but also to an environmental crisis. These differences depend on the world-view and they are also a function of the state of knowledge, the consideration of uncertainty for policy-making, the assessment of the significance of the impacts, the selection of indicators or the demarcation of the specific system of interest and the policy-objective, as well as of the scale to be considered.

In the frame of the ALARM project, a redefinition of the DPSIR categories is proposed, aiming to reflect on these complex situations by better acknowledging different legitimate perspectives and narratives. This is achieved by, on the one hand, allowing alternative descriptions and making visible the differences in positions among stakeholders and, on the other hand, by taking into consideration social and political aspects besides the economic and environmental spheres.

Article 4: ’Transgenic Treadmill’: Responses to the emergence and spread of Glyphosate-Resistant Johnsongrass in Argentina

The broad-spectrum herbicide glyphosate has become the largest-selling crop-protection product worldwide. Over the last years, the agricultural use of glyphosate has risen due to price reductions, to an increase in supply associated with patent expiration, to further implementation of minimum and non-tillage practices and to the adoption of genetically modified (GM) glyphosate-resistant (GR) cultivars.

Although it was initially considered a low-risk herbicide for weed-resistance, the use of glyphosate has been in the last years associated to the appearance of a growing number of tolerant or resistant weeds, with socio-environmental consequences besides loss of productivity. Herbicide-resistant weeds associated to an increased consumption of glyphosate by GR cropping systems have become one of the main ecological risks discussed in the literature on GMOs.

In 2002, a glyphosate-resistant biotype of johnsongrass (*Sorghum halepense* (L.)) appeared in Argentina, where over 16 million hectares are devoted to GM glyphosate-resistant soybeans. The invasion is covering in 2008 at least 10.000 hectares. In this paper this case was reviewed, discussing the associated management strategies through an analysis of the political, economic and institutional driving forces leading to this phenomenon. We also devoted part of the paper to analyse the consequences for rural dynamics, starting from the environmental history of the weed in Argentina.

In general, the neo-liberal approach to agriculture is one where the determination of the agrarian dynamics and changes is left to the free market. This is done by means of dumping decisions to the individual sphere, and by setting self interested free choice as the only way of safeguarding rights and liberties. The same reasoning operates regarding weed management resistance. However, the social consequences from the application of this approach to weed resistance management have been under-explored. Two approaches summarize the different attitudes for managing weed resistance. The first one is identified with “proactive” or “preventive” management, and includes identifying major pathways and changing environmental conditions to reduce the likelihood of future resistance. The second one is known as “reactive management”, and implies actions which aim at reducing the costs of weed resistance by changing the herbicide when it stops controlling the pest, applying the most cost-efficient technology at any given time. These two strategies are also known as mitigation and adaptation.

The aim of this paper was to analyze the driving forces behind the initial spread of GR johnsongrass and the social, economic and environmental implications that pre-emptive or reactive biosecurity strategies have at a societal level. Reasons behind farmers’ willingness or reluctance to adopt preventive resistance management strategies are also discussed, as well as the institutional conditions and constraints. The existence of a new form of treadmill phenomenon, not only leading to the increase of herbicide use but also to the intensification in the use of GM crops, was also explored.

Final remarks

The four articles presented in this thesis converge in the idea that socio-economic considerations on biosafety are becoming major issues in the environmental agenda. However, they also show that there are still serious disputes on how to handle and integrate them.

This PhD starts from the importance of incorporating the different stakeholders' points of view and values when approaching to biosafety issues. The different cases point to the existence of different perspectives concerning the studied topics. In spite of it, both IS and GMOs are usually managed in a technical way, without taking into account the different perceptions and concepts and without analysing the context of application. The articles submitted here show that these divergent –and often conflicting- perceptions are rooted in a clash of rationales or world-views, usually leading to divergent development proposals and policy actions, which cannot be only discussed in a technical manner. In that sense, this thesis suggests that biosafety governance needs to be broadened in order to allow questioning not only if something is safe or if the benefits are proportionate to the costs but also if it is desirable, meaningful and contributes to the sort of future we want. In that sense, biosafety governance should not only focus on the means, but also on the objectives to be achieved.

This implies bringing into the decision-making process the stakeholders' perspectives. Participation influences the legitimacy of decisions, but it also improves the knowledge of the problem by expanding the boundaries of the system. This suggestion, in line with the so-called “post-normal science” (Funtowicz and Ravetz, 1994), can help in focusing the attention to the socially-relevant aspects, democratising both the processes of conducting research and of taking decisions. The integratation of socio-economic aspects responds also to a quality requirement and to the need to rethink the relationship between science and policy (Funtowicz and Strand, 2007).

Update of the case studies

Since some of the articles were written in the last three years, some changes have been occurred since then. This section aims to update the findings of this PhD by shortly describing them.

After the publication of the first article of this thesis, the zebra mussel has spread through the Spanish river basins (Rodríguez-Labajos et al., 2008), including the main course of the Ebro River and some of its tributaries, the Jucar and Segura. Since 2006, the Catalan

Water Agency launched a regional strategy to control the zebra mussel, which integrated results obtained from the development of participatory scenarios within ALARM project (led by Beatriz Rodríguez-Labajos).

Some other changes are related to the GM coexistence issue in Catalonia and Aragon. After the two articles on this issue of this PhD were written, the Catalan Organic Certification Body (CCPAE) published, for the first time, the data on the surface of organic maize for the last years. It documented the existence of 34 hectares of maize in 2007 (CCPAE, 2008), which represents a decrease of 65% since 2001, In the 2008 campaign, only 5 hectares of organic maize are left in Catalonia[10]. These data confirm the trend noticed in the articles, putting the Catalan figures on a level with the results in Aragon. Meanwhile, in recent statements, the Ministry of Agriculture assured that it is not going to regulate the coexistence issue for the moment, "due to the difficulty for establishing a norm"[11] while it waits that the dispute between the Member States (or Regions) and the European Commission for the authority to establish coexistence measures is solved (Lee, 2008).

Finally, regarding the GR johnsongrass case, major changes could occur during the next months. In that sense, the decline of commodity prices including soybeans during the second half of 2008 might lead to a questioning of the export-led growth model. From July to October 2008 soybean price lost 45% of its value[12]. In Argentina, this has been translated in a sharp fall in land sales and leasing rents. Small producers, despite the low prices, "are forced to it (sell land) as they are afraid of losing all what they have"[13], which will reinforce the trend towards land concentration described in the fourth paper of the thesis.

---

[10] Dani Valls, CCPAE president, interviewed by El País, 21st October 2008; pp. 37.

[11] Francisco Mombiela, director for Industry and Food Markets, interviewed by El País, 21st October 2008; pp. 37.

[12] "El precio de la soja cayó más de 45% por la crisis global". Tiempo Pyme, 11th October. Available at: http://www.tiempopyme.com/despachos.asp?cod_des=61306&ID_Seccion=128 (retrieved 27th October 2008).

[13] "Con la caída del precio de la soja, se desplomó la venta de campos". Available at: www.puntal.com.ar (retrieved 27th October 2008).

References

Alderman, D.H., 2004. Channing Cope and the making of a miracle vine. The Geographical Review, 94(2): 157-177.

Altieri, M.A., 2005. The myth of coexistence: Why transgenic crops are not compatible with agroecologically based systems of production. Bulletin of Science, Technology and Society, 25: 361–371.

Angulo, E., Gilna, B., 2008. When biotech crosses borders. Nature Biotechnology, 26(3): 277-282.

Arcioni, E., 2004. What's in a Name? The Changing Definition of Weeds in Australia. Environmental and Planning Law Journal, 21: 442-457.

Barbier, E.B., 2001. A note on the economics of biological invasions. Ecological Economics, 39: 197-202.

Barratt, B.I.P., Moeed, A., Malone, L.A., 2006. Biosafety assessment protocols for new organisms in New Zealand: Can they apply internationally to emerging technologies? Environmental Impact Assessment Review, 26: 339– 358.

Barton, J.E., Dracup, M., 2000. Genetically Modified crops and the environment. Agronomic Journal, 92: 797–803.

Beinart, W., Middleton, K., 2004. Plant transfers in historical perspective. A review article. Environment and History, 10: 3-29.

Beinart, W., 2008. Costs and benefits of plant transfers and bioinvasions in historical perspective with particular reference to Africa. Proceedings of the 10th Biannual International Society for Ecological Economics Conference, ISEE 2008, Nairobi.

Binimelis, R., Born, W., Monterroso, I., Rodríguez-Labajos, B., 2007. Socio-economic impact and assessment of biological invasions. In Nentwig, D. (ed), Biological invasions. Ecological studies,193, Springer-Verlag, Berlin and Heidelberg, pp. 331-347.

Born, W., Rauschmayer, F., Bräuer, I., 2005. Economic evaluation of biological invasions -a survey. Ecological Economics, 55: 321-336.

Bright, C., 1999. Invasive species: pathogens of globalization. Journal of Foreign Policy, 116: 50-64.

British Medical Association, 2004. GM foods and health: a second interim statement. Board of Science and Education, London.

Buttel, F.H., Kenney, M., Kloppenburg, J.R.Jr., 1985. From Green Revolution to Biorevolution: Some observations on the changing technological bases of economic transformation in the Third World. Economic Development and Cultural Change, 34(1): 31-55.

Carr, S. Levidow, L., 2000. Exploring the links between science, risk, uncertainty and ethics in regulatory controversies about genetically modified crops. Journal of Agricultural and Environmental Ethics, 12: 29–39.

Cassey, P., Blackburn, T.M., Duncan, R.P., Chown, S.L., 2005. Concerning invasive species: Reply to Brown and Sax. Austral Ecology, 30(4): 475-480.

CBD, 2002. Review of options for the implementation of article 8(h) on alien species that threaten ecosystems, habitats or species. Addendum, use of terms. Sixth Meeting of the International Convention of Biological Diversity. Secretariat of the Convention on Biological Diversity, United Nations Environment Programme.

CCPAE, 2008. Revista del Consell Català de la Producció Agrària Ecològica, 4.

CPB, 2000. Cartagena Protocol on Biosafety to the Convention on Biological Diversity. Text and annexes. Secretariat of the Convention on Biological Diversity, Montreal. Available at: http://www.cbd.int/biosafety/protocol.shtml

Coates, P., 2003. Editorial Postscript: the naming of strangers in the landscape. Landscape Research, 28(1): 131-137.

Cocklin, C., Dibden, J., Gibbs, D., 2008. Competitiveness versus "clean and green"? The regulation and governance of GMOs in Australia and the UK. Geoforum, 39: 161-173.

Cook, D., Proctor, W., 2007. Assessing the threat of exotic plant pests. Ecological Economics, 63: 594-604.

Crosby, A.W., 1986, Ecological Imperialism: The Biological Expansion of Europe, 900–1900. Cambridge University Press, Cambridge.

Daehler, C.C., 2001. Two Ways to be an invader, but one is more suitable for ecology. Bulletin of the Ecological Society of America, 82: 101-102.

Dalmazzone, S, 2000. "Economic Factors Affecting Vulnerability to Biological Invasions". In Perrings, C., Williamson, M., Dalmazzone, S. (eds.) The economics of biological invasions. Edward Elgar Publishing, Cheltenham, pp 17–30.

Daño, E.C., 2007. "Potencial socio-economic, cultura and ethical impacts of GMOs: Prospects for socio-economic impact assessment". In Traavik, T., Lim, Ching, L., (eds). Biosafety First – Holistic approaches to risk and uncertainty in genetic engineering and genetically modified organisms. Tapic Academic Press, Trondheim.

Davis, M.A., Thompson, K., 2000. Eight ways to be a colonizer; two ways to be an invader: A proposed nomenclature scheme for invasion ecology. Bulletin of the Ecological Society of America, 81(3): 226-230.

Davis, M.A., Thompson, K., 2001. Invasion terminology: Should ecologists define their terms differently than others? No, not if we want to be of any help! Bulletin of the Ecological Society of America, 82(3): 206.

De Wit, M.P., Crookes, D.J, Van Wilgen, B.W., 2001. Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. Biological Invasions, 3 (2): 167-178.

Devos, Y., Maeseele, P., Reheul, D., Vanspeybroeck, L., de Waele, D., 2008. Ethics in the societal debate on genetically modified organisms: a (re)quest for sense and sensibility. Journal of Agricultural and Environmental Ethics, 21(1): 29-61.

Domingo, J.L., 2000. Health Risks of GM Foods: Many Opinions but Few Data. Science, 288(5472): 1748 – 1749.

Duffy, 2001. Who benefits from biotechnology? Paper presented at the American Seed Trade Association Meeting. December, Chicago.

Ervin, D.E., Welsh, R., Batie , S.S., Carpentier, C.H., 2003. Towards an ecological systems approach in public research for environmental regulation of transgenic crops. Agriculture, Ecosystems and Environment, 99: 1-14.

European Commission, 2002. Life sciences and biotechnology – A strategy for Europe. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. COM(2002) 27. Office for Official Publications of the European Communities, Luxembourg.

Evans, J.M., Wilkie, Ann C., Burkhardt, J., 2008. Adaptative management of nonnative species: moving beyond the "either-or" through experimental pluralism. Journal of Agricultural and Environmental Ethics. Online first, available at: http://www.springerlink.com/content/102919/?Content+Status=Accepted

Ewel, J.J., O'Dowd, D.J., Bergelson, J., Daehler, C.C., D'Antonio, C.M., Diego Gómez, L., Gordon, D.R., Hobbs, R.J., Holt, A., Hopper, K.R., Hughes, C.E., LaHart, M., Leakey, R., Lee, W.G., Loope, L.L., Lorence, D.H., Louda, S.M:, Lugo, A.E., McEvoy, P.B., Richardson, D.M., Vitousek, P.M., 1999. Deliberate introductions of species: research needs. BioScience, 49(8): 619-630.

FAO, 2003. Biosecurity in Food and Agriculture Discussion Paper, COAG/2003/9. Committee on Agriculture, 17th Session, Rome, April. Available at: http://www.fao.org/DOCREP/MEETING/006/Y8453E.HTM (retrieved 20th August 2008).

Fransen, L., la Viña, A.G.M., Dayrit, F., Gatlabayan, L., Santosa, D.A., Adiwibowo, S., 2005. Integrating socio-economic considerations into biosafety decisions: the role of public participation. White Paper, World Resources Institute, Washington.

Funtowicz, S., Ravetz, J.R., 1994. The worth of a songbird: ecological economics as a post-normal science. Ecological Economics, 10: 197-207.

Funtowicz, S., Strand, R., 2007. Models of Science and Policy. In Traavik, T., Lim, L.C. (eds.) Biosafety First: Holistic Approaches to Risk and Uncertainty in Genetic Engineering and Genetically Modified Organisms. Tapir, Trondheim, pp 263-278.

Gaskell, G., Allum, N., Stares, S., 2003. Europeans and Biotechnology in 2002. Eurobarometer 58.0. A report to the EC Directorate General for Research from the project 'Life Sciences in European Society' QLG7-CT-1999-00286.

Hancock, J.F., 2003. A framework for assessing the risk of transgenic crops. BioScience, 53(5): 512-519.

Hajer, M., 1995. The politics of environmental discourse. Ecological modernization and the policy process. Oxford University Press, Oxford.

Hall, M., 2003. Editorial: The Native, Naturalized and Exotic -plants and animals in human history. Landscape Research, 28(1): 5-9.

Heller, C., 2002. From scientific risk to paysan savoir-faire: Peasant expertise in the French and global debate over GM crops. Science as Culture, 11: 5–37.

Heller, C., 2006. Post-industrial “quality agricultural discourse”: Techniques of governance and resistance in the French debate over GM crops. Social Anthropology, 14(3): 319–334.

Herring, R.J., 2008. Opposition to transgenic technologies: ideology, interests and collective action frames. Nature Reviews Genetics 9, 458 – 463.

Horan, R.H., Perrings, C., Lupi, F., Bulte, E.H., 2002. Biological pollution prevention strategies under ignorance: The case of invasive species. American Journal of Agricultural Economics, 84(5): 1303-1310.

Hulme, P.E., Bacher, S., Kenis, M., Klotz, S., Kuhn, I., Minchin, D., Nentwig, W., Olenin, S., Panov, V., Pergl, J., Pysek, P., Roques, A., Sol, D., Solarz, W., Vilà, M., 2008. Grasping at the routes of biological invasions: a framework for integrating pathways into policy. Journal of Applied Ecology, 45(2).: 403-414.

IFOAM, 2002. Position on genetic engineering and genetically modified organisms. Available at: http://www.ifoam.org/press/positions/ge-position.html (retrieved 30th October 2008).

IUCN – The World Conservation Union, 2000. IUCN guidelines for the prevention of biodiversity loss due to biological invasion (approved by the IUCN Council, February, 2000)

Jay, M., Morad, M., 2006. The socioeconomic dimensions of biosecurity: the New Zealand experience. International Journal of Environmental Studies, 63(3), 293-302.

Jensen, K.K., Gamborg, C., Madsen, K.H., Jørgensen, R.B., von Krauss, M.K., Folker, A.P., Sandøe, P., 2003. Making the EU ”Risk Window” transparent: The normative foundations of the environmental risk assessment of GMOs. Environmental Biosafety Research, 3: 161-171.

Kelle, U., 2000. Computer-assisted analysis: coding and indexing. In: Bauer, M.W., Gaskell, G., (eds). Qualitative Researching with Text, Image and Sound. Sage, London, pp. 282-298.

Kleinman, D.L., Kinchy, A.J., 2007. Against the neoliberal steamroller? The Biosafety Protocol and the social regulation of agricultural biotechnologies. Agriculture and Human Values, 24: 195–206.

Kloppenburg, J.R., 1988. First the seed. The political economy of plant biotechnology, 1492-2000. Cambridge University Press, Cambridge.

Kolar, C.S., Lodge, D.M., 2001. Progress in invasion biology: predicting invaders. Trends in Ecology & Evolution, 16(4): 199-204.

Kondoh, K., Jussame, R.A., 2006. Contextualizing farmers' attitudes towards genetically modified crops. Agriculture and Human Values, 23: 341-352.

Köster, V., 2001. A New Hot Spot in the Trade-Environment Conflict. Environmental Policy and Law, 31(2): 82-94.

Kowarik, I., 2003. Human agency in biological invasions. Secondary releases foster naturalisation and population expansion of alien plant species. Biological Invasions, 5: 293–312.

Kropiwnicka, M., 2003. Biotechnology and food security in developing countries. The case for strengthening international environmental regimes. ISYP Journal on Science and World Affairs, 1(1): 59-81.

Kvakkestard, V., Gillund, F., Kjølberg, K.A., Vatn, A., 2007. Scientists' Perspectives on the Deliberate Release of GM Crops. Environmental Values, 16: 79–104.

Kvale, S., 1996. InterViews. An Introduction to Qualitative Research Interviewing. Sage, Thousand Oaks.

Larson, B.M.H., Nerlich, B., Wallis, P., 2005. Metaphors and biorisks: The war on infectious diseases and invasive species. Science Communication, 26: 243- 268.

Larson, B.M.H., 2007a. An alien approach to invasive species: objectivity and society in invasion biology. Biological Invasions, 9: 947–956.

Larson, B.M.H., 2007b. Who's invading what? Systems thinking about invasive species. Canadian Journal of Plant Science, 87: 993-999.

Larson, B.M.H., 2007c. Thirteen ways of looking at invasive species. In Clements, D.R., Darbyshire, S.J. (eds). Invasive plants: Inventories, strategies and action. Topics in Canadian Weed Science, 5. Canadian Weed Science Society – Société canadienne de malherbologie, Sainte Anne de Bellevue, Québec, pp. 131-156.

Lee, M., 2008. The governance of coexistence between GMOs and other forms of agriculture : A purely economic issue ? Journal of Environmental Law, 20(2): 193-212.

Levidow, L., Marris, C., 2001. Science and governance in Europe: Lessons from the case of agricultural biotechnology. Science and Public Policy, 28(5): 345–360.

Levidow, L., Boschert, K., 2007. Coexistence or contradiction? GM crops versus alternative agricultures in Europe. Geoforum, 39(1): 174-190.

Levidow, L., Carr, S., 2007. GM crops on trial: Technological development as a real-world experiment. Futures, 39: 408–431.

Levine, J.M., Vilà, M., D'Antonio, C., Dukes, J.S., Grigulis, K., Lavorel, S., 2003. Mechanisms underlying the impacts of exotic plant invasions. Proceedings Royal Society of London, B., 270: 775–781.

Lewins, A., Silver, C., 2007. Using software in Qualitative Research. Sage, London.

Lodge, D.M., Schrader-Frechette, K., 2003. Nonindigenous species: Ecological explanation, environmental ethics, and public policy. Conservation Biology, 17(1): 31-37.

Lyson, T.A., 2002. Advanced agricultural biotechnologies and sustainable agriculture. Trends in Biotechnology 20(4): 193-196.

Mackenzie, R., Burhenne-Guilmin, F., la Viña, A.G.M., Werksman, J.D., Ascencio, A., Kinderlerer, J., Kummer, K., Tapper, R., 2003. An Explanatory Guide to the Cartagena Protocol on Biosafety. IUCN Environmental Policy and Law Paper, 46. IUCN, Gland and Cambridge.

Marris, C., Wynne, B., Simmons, P., Weldon, S., Cáceres, J., De Marchi, Br., Klinke, A., Lemkow, L., Pellizzoni, L., Pfenning, U., Renn, O., Sentmartí, R., Public perceptions of agricultural biotechnologies in Europe. Final Report of the PABE research project (FAIR CT98-3844). Commission of European Communities.

Martínez-Ghersa, M.A., Worster, C.A. and Radosevich, S.R., 2003. Concerns a Weed Scientist Might Have About Herbicide-Tolerant Crops: A Revisitation. Weed Technology, 17: 202–210.

Mayer, S., Stirling, A., 2004. GM crops: good or bad? EMBO Reports, 5: 1021-1024.

McAfee, K., 2003. Neoliberalism on the molecular scale. Economic and genetic reductionism in biotechnology battles. Geoforum 34, 203-219.

McAfee, K., 2008. Beyond techno-science: Transgenic maize in the fight over Mexico's future. Geoforum 39, 148–160.

McNeely, J.A., 2000. Global strategy for addressing the problem of invasive alien species. A result of the Global Invasive Species Programme (GISP).

McNeely, J.A., Mooney, H.A., Neville, L.E., Schei, P., Waage, J.K. (eds.), 2001. A global strategy on invasive alien species. IUCN Gland and Cambridge, x + 50 pp.

Melville, E.G.K., 1994. A plague of sheep: environmental consequences of the conquest of Mexico. Cambridge University Press; Cambridge, New York & Melbourne.

Meyerson, L.A., Reaser, J.K., 2002. Biosecurity: moving toward a comprehensive approach. BioScience, 52(7): 593-600.

Monterroso, I., 2005. Comparison of two socio-economic assessment methods for the analysis of the invasion process of *Hydrilla verticillata* in Lake Izabal, Guatemala. Master thesis, Universitat Autònoma de Barcelona, Bellaterra. Available at: http://www.selene.uab.es/brodriguezl

Monterroso, I., Rodríguez-Labajos, B., Binimelis, R., 2005. Conceiving biological invasions as an environmental issue: The need for deliberation processes. Paper presented at the International Conference of Sociology "Environment, knowledge and democracy", 6th and 7th July, Marseille.

Müller, W., 2003. Concepts for coexistence. ECO-RISK, Office of Ecological Risk Reseach, commissioned by the Federal Ministry of Health and Women.

Norgaard, K.M., 2007. The Politics of Invasive Weed Management: Gender, Race, and Risk Perception in Rural California. Rural Sociology, 72(3), 450–477.

Parker, I.M., Kareiva, P., 1996. Assessing the risks of invasion for genetically engineered plants: Acceptable evidence and reasonable doubt. Biological Conservation, 78: 193-203.

Perrings, C., Williamson, M., Barbier, E. B., Delfino, D., Dalmazzone, S., Shogren, J., Simmons, P., Watkinson, A., 2002. Biological invasion risks and the public good: an economic perspective. Conservation Ecology 6(1): 1. [online] URL: http://www.consecol.org/vol6/iss1/art1

Perings, C., 2005. Mitigation and adaptation strategies for the control of biological invasions. Ecological Economics 52(3): 315-325.

Perrings, C., Dehnen-Schmutz, K., Touza, J., Williamson, M., 2005. How to manage biological invasions under globalization. Trends in Ecology and Evolution, 20(5), 212-215.

Pimentel, D., Lach, L., Zuniga, R., Morrison, D., 2000. Environmental and Economic Costs of Nonindigenous Species in the United States. BioScience, 50(1): 53-65.

Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T., Tsomondof, T., 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems and Environment, 84: 1–20.

Pimentel, D., Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics, 52: 273–288.

Ponti, L., 2005. Transgenic crops and sustainable agriculture in the European context. Bulletin of Science Technology Society, 25: 289–305.

Powles, S. B., 2003. My view. Weed Science, 51: 471.

Pryme, I.P., Lembcke, R., 2003. In vivo studies on possible health consequences of genetically modified food and feed -with particular regard to ingredients consisting of genetically modified plant materials. Nutrition and Health, 17: 1-8.

Pyŝek, P., Richardson, D.M., Rejmánek, M., Webster, G.L., Williamson, M., Kirschner, J., 2004. Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. Taxon 53(1):131–143.

Quist, M.C., Hubert, W.A., 2004. Bioinvasive species and the preservation of cutthroat trout in the western United States: ecological, social and economic issues, Environmental Science & Policy, 7(4): 303-313.

Richardson, D.M., Pyšek, P., Rejmánek, M., Barbour, M.G., Panetta, F.D., West, C.J., 2000. Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions, 6: 93-107.

Robbins, P., 2004. Comparing invasive networks: cultural and political biographies of invasive species. The Geographical Review, 94(2): 139-156.

Rodríguez-Labajos, B., 2006. Interlinked biological invasions in the Ebro River. A multi-scale scenario approach. Master thesis, Universitat Autònoma de Barcelona, Bellaterra. Available at: http://www.selene.uab.es/brodriguezl

Rodríguez-Labajos, B., Binimelis, R., Martínez-Alier, J., Munnè, A., 2008. Reciente pero rápida invasión del mejillón cebra en los ríos españoles. In Vilà, M., Valladares, F., Traveset, A., Santamaría, L., Castro, P. (eds.), Invasiones Biológicas, serie Ciencia y Divulgación, CSIC.

Roff, R.J., 2008. Preempting to nothing: neoliberalism and the fight to de/re-regulate agricultural biotechnology, Geoforum, 39: 1423–1438.

Sarewitz. D., 2004. How science makes environmental controversies worse. Environmental Science and Policy, 7: 385-403.

Scoones, I., 2008. Mobilizing against GM crops in India, South Africa and Brazil. Journal of Agrarian Change, 8(2/3): 315-344.

Shafroth, P.B., Cleverly, J.R., Dudley, T.L., Taylor, J.P., Van Ripper III, C., Weeks, E.P., Stuart, J.N., 2006. Control of *Tamarix* in the Western United States: Implications for water salvage, wildlife use, and riparian restoration, Environmental Management, 35(3):231-246.

Shine, C., Williams, N., Gündling, L., 2000. A Guide to Designing Legal and Institutional Frameworks on Alien Invasive Species. International Union for Conservation of Nature (IUCN), Environmental Policy and Law Paper, 40. Gland and Cambridge.

Shrader-Frechette K., 2001. Non-indigenous species and ecological explanation. Biology and Philosophy, 16: 507–519.

Simberloff, D., 2003. Confronting introduced species: a form of xenophobia? Biological Invasions, 5:179-192.

Snow, A.A., Andow, D.A., Gepts, P., Hallerman, E.M., Power, A., Tiedje, J.M., Wolfenbarger, L.L., 2004. Genetically engineered organisms and the environment: current status and recommendations. ESA Position Papers, Ecological Society of America (ESA), Public Affairs Office, Washington.

Stabinsky, D., 2000. Bringing Social Analysis Into a Multilateral Environmental Agreement: Social Impact Assessment and the Biosafety Protocol. The Journal of Environment Development, 9: 260-283.

Steinbrecher, R.A., 2001. Ecological consequences of genetic engineering. In Tokar, (Ed.) Redesinging life? The worldwide challenge to genetic engineering. Zed Books, London, pp. 75-102.

Stokes, K.E., O'Neill, K.P., Montgomery, W.I., Dick, J.T.A., Maggs, C.A., McDonald, R.A., 2006. The importance of stakeholder engagement in invasive species management: a cross-jurisdictional perspective in Ireland, Biodiversity and Conservation, 15 (8): 2829–2852.

Sunshine Project, 2003. Biosafety, biosecurity, and biological weapons. A background paper on three agreements on biotechnology, health and the environment, and their potential contribution to biological weapon control. Hamburg, Germany. Available at: www.sunshine-project.org

Theodoropoulos, D.I., 2003. Invasion biology. Critique to a pseudoscience. Avvar Books, Blythe, California.

Third World Network, 2008. Assessing the socio-economic, cultural and ethical impacts of GMOs. Briefings for MOP 4, 3. Bonn, Germany.

Tiedje, J.M., Colwell, R.K., Grossman, Y.L., Hodson, R.E., Lenski, R.E., Mack, R.N., Regal, P.J., 1989. The Planned Introduction of Genetically Engineered Organisms: Ecological Considerations and Recommendations. Ecology, 70(2): 298-315.

Traavik, T., Heinemann, J., 2007. Genetic engineering and omitted health research: Still no answers to ageing questions. TWN Biotechnology & Safety Series, 7. Third World Network, Penang.

Verhoog, H., 2007. Organic agriculture versus genetic engineering. Netherlands Journal of Agricultural Science, 54 (4): 387–400.

Vilà, M., Pujadas, J., 2001. Land-use and socio-economic correlates of plant invasions in European and North African countries. Biological Conservation, 100: 397–401.

Waage J.K., 2005. A new agenda for biosecurity. A New Agenda for Biosecurity. Draft Report for the Department for Food, Environment and Rural Affairs. Faculty of Life Sciences, Imperial College, London.

Waage, J.K., Mumford, J.D., 2008. Agricultural biosecurity. Philosophical Transactions of the Royal Society B, 363: 863–876.

Walter, M., Binimelis, R., (unpublished). The multiple meanings of the *Cameraria ohridella* biological invasion in Paris' green areas.

Williamson, M., 1993. Invaders, weeds and the risk from genetically manipulated organisms. Experientia, 49(3): 219-224.

Williamson, M., 1994. Community response to transgenic plant release – Predictions from British experience of invasive plants and feral crop plants. Molecular ecology, 3(1): 75-79.

Williamson, M., 1996. Biological invasions. Chapman and Hall, London, 244 pp.

Wolfenbarger, L.L., Phifer, R.B., 2000. The Ecological Risks and Benefits of Genetic Engineering Plants. Science, 290: 2088-2093.

Wu, F., 2004. Explaining public resistance to genetically modified corn: an analysis of the distribution of the benefits and risks. Risk Analysis, 24(3): 715-726.

Wynne, B., 2001. Creating public alienation: Expert Cultures of Risk and Ethics on GMOs. Science as Culture, 10(4): 445 – 481.

Article 1:

A Social Analysis of the Bioinvasions of *Dreissena polymorpha* in Spain and *Hydrilla verticillata* in Guatemala

Published in Environmental Management

Environ Manage (2007) 40:555–566
DOI 10.1007/s00267-006-0206-x

A Social Analysis of the Bioinvasions of *Dreissena polymorpha* in Spain and *Hydrilla verticillata* in Guatemala

Rosa Binimelis · Iliana Monterroso · Beatriz Rodríguez-Labajos

Received: 16 June 2006 / Accepted: 21 March 2007

Abstract Human agency plays a key role in the processes of biological invasions. This comprises not only the human role in the configuration of driving forces or in the perception of the impacts, but also the conceptualization of alien species themselves as an environmental problem. This paper examines different stakeholders' positions in bioinvasion processes at different scales, and it looks at their relevance for the management of invasive species. It compares two cases: the invasion process of *Dreissena polymorpha* in the Ebro River in Spain and the case of *Hydrilla verticillata* in Lake Izabal, Guatemala. Our results are structured according to impacts and to management options. The discussion focuses on the relevance of incorporating the different stakeholders' interests and values in the analysis and management of biological invasions. Although social analysis of stakeholders' positions is necessary in order to foster management actions, it also reveals conflicts on the relevant criteria and on the very definition of invasive species.

Keywords Invasive species · Biodiversity conservation · Stakeholders · Social analysis · *Hydrilla verticillata* · *Dreissena polymorpha* · Ebro River · Lake Izabal

Introduction

Biological invasions are highlighted as major causes of biodiversity loss, playing a key role in global environmental change (Vitousek and others 1996, 1997, OTA 1993, Sala and others 2000). Therefore, the subject has become significant for conservation policy. For instance, the Convention on Biological Diversity (CBD 2002) states that ''each contracting party shall, as far as possible, and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species.''

Invasion processes are considered a human-induced phenomenon. This human involvement comprises not only the configuration of driving forces (Dalmazzone 2000, Kowarik 2003), the perception of the impacts (Levine and others 2003), and the implementation of responses (McNeely and others 2001), but also the very conception of the invasive process as an environmental and socio-economic problem (Shrader-Frechette 2001).

In spite of this multiplicity of social elements, knowledge of biological invasions has been mostly influenced by the scientific approaches of biogeography and ecology (Pyšek and others 2004, Shine and others 2000, Williamson 1996). Research in these fields has examined invasiveness of the species and invasibility of the ecosystems. These studies have successfully contributed to increased knowledge on the ecological and biological factors in the process of invasion. The social analysis of bioinvasions, particularly from the economic perspective, counts with the influential work developed by Pimentel and others (2001, 2005) and Perrings and others (2000). The present paper is a contribution from social research. Its main objective consists of examining the positions of different stakeholders in relation to invasive species, and discussing how such social analysis can help in managing bioinvasions.

This article draws upon the literature on sustainability that emphasizes complexity and the legitimacy of different criteria for evaluation, uncertainty, and the emergence of

R. Binimelis (✉) · I. Monterroso · B. Rodríguez-Labajos
Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, Campus UAB, Ed. Ciències; Torre 5 (parells), 4 pl., 08193 Barcelona, Bellaterra, Spain
e-mail: rosa.binimelis@uab.cat

different issues at different temporal and geographical scales (Ravetz 1971, Strand 2002, Munda 2003, Rauschmayer 2003, Giampietro 2004). Invasive species occur at a local scale, but many drivers act at a large scale: for instance, the intensification of global trade, the utilization of faster means of transport, or the expansion of industrial agriculture (McNeely and others 2001). Therefore, for policy actions, multidisciplinary approaches are needed to link these drivers with the specific impacts of the species at local level in order to be able to meet the challenge of these global-local relations (Giampietro 2004).

The paper is structured in four main sections. The first introduces the issue of biological invasions, with special emphasis on the definitions used in the literature. The following section explains the two case studies, starting with a description of the analyzed species in order to display relevant ecological features of both invasion processes. Socio-economic and environmental characteristics of host ecosystems are then discussed in order to establish interactions between the conditions of recipient ecosystems (invasibility) and the invasive species that explain establishment and could favor further spread. In the third section, an analysis of stakeholders is presented showing how they value the multidimensional impacts and effects of the invasion process. Social groups participate as drivers, as affected by the invasions and as promoters of management options. A brief description of the relevant management alternatives in the two cases is presented. A key aspect of this analysis is the discussion of the appropriate scale and how it should be delimited.

Biological Invasions as a Complex Phenomenon

Biological invasions are framed by different interpretations of this phenomenon. Thus, a range of definitions is used to try to describe these processes, usually by taking into account ecological and/or socioeconomic as well as temporal and geographic aspects. A literature review of the definition of alien invasive species suggests three groups of definitions.

A first group of definitions highlights the ecological and biogeographic aspects, such as spatial distribution and/or population trends. Daehler's definition of alien invasive species serves as an illustration: ''those species that intentionally and unintentionally spread in new habitats aided by human agency at high growth rates, trespassing new habitats after the Neolithic era'' (Daehler 2001, Pyšek and others 2004).

A second group of definitions is guided by policy objectives that emphasize mitigation of negative impacts on biological diversity, human welfare, or both (Shine and others 2000, McNeely and others 2001, Davis and Thompson 2000, 2001). This is the approach used by the CBD (2002) to define invasive species: ''alien species that threaten ecosystems, habitats or species with economic or environmental harm.''

Lastly, a third notion considers the concept of alien invasive species as a social construction inspired by nativism, a discriminative ideology based on personal or cultural values (Theodoropoulos 2003). This author illustrates with examples his view on the economic interests (e.g., control-related chemical industry) behind an overstated consideration of biological invasions as threats to welfare. A main conclusion of Theodoropoulos' controversial book is the collusion of the scientific community with such economic interests and cultural values (Simberloff 2003a).

The differences in the conceptualization of invasive species will determine what policy options are to be taken and which are the targeted species, if any. The first type of definition is claimed as value free (Daehler 2001). However, it is still context dependent because the notion of alien entails the delimitation of temporal and geographic boundaries (Davis and Thompson 2000). Moreover, some degree of arbitrariness is inherent in the idea of over-abundant introduced species (Shrader-Frechette 2001). Furthermore, aside from the problem of boundaries delimitation, focusing on all introduced species promotes the notion that they are intrinsically less desirable than native species (Simberloff 2003b). In policy terms, the issue is still open to subjectivity, as decisions are taken regarding which species should be managed. The obvious budget limitations require prioritization.

A historical approach also reveals changes in subjective perceptions. While Crosby (1986) points out an ''ecological imperialism'' in America, Australia, and New Zealand, tied to the transport of biota—including pathogens and weeds—by the Europeans, other species have been historically considered beneficial. This is the case with many introduced crops, such as maize in the food system of some European and African regions (Pimentel and others 2001). In addition, some species can be judged as beneficial during a period and damaging afterward, as economically profitable but environmentally harmful (like black wattle (*Acacia mearnsii*) in South Africa (de Wit and others 2001)), or as having positive and negative impacts on the same dimension at the same time. For instance, saltcedar (genus *Tamarix*) is reported to have negative ecological impacts such as the displacement of native vegetation or increased soil salinization while at the same time it can control erosion (Shafroth and others 2006).

The present study is based on the analysis of two cases, which allow the comparison of invasion processes in two aquatic ecosystems. The two cases are examples not of successful prevention but of ex-post attempts to manage the invasion.

A Comparative Approach to Invasion Processes

Methodology

The investigation was divided into three phases. The first involved the collection of socio-economic and historical information regarding the areas of study and the development of the invasion processes. Institutional analysis tools were used during this phase. Then, information was processed and compared in the two aquatic systems in order to identify factors associated with vulnerability of recipient ecosystems, and the socio-economic conditions of affected areas. Socio-economic and biological information was used for classifying groups of stakeholders and analyzing their perception of impacts on environmental functions.

The objective of the third phase was to come up with those management alternatives supported by the different groups of stakeholders. Common aspects in the responses to the invasion processes were identified. To this aim, participatory techniques involving local people in the research process included workshops, semistructured group and individual in-depth interviews, and also participant observation. Qualitative techniques were selected for their usefulness in obtaining in-depth information as well as promoting the participation of different groups.

Description of the Case Studies

An ex-post analysis was conducted for two cases of biological invasions in aquatic ecosystems: one in the Mediterranean Ebro region of Spain, the other in the tropical region of Lake Izabal in Guatemala. The studied species were the zebra mussel (*Dreissena polymorpha*) and the macrophyte hydrilla (*Hydrilla verticillata*), respectively. Both species are listed in the Global Invasive Species Program database among the 100 most noxious invasives of the world (http://www.issg.org/database). Introduction was accidental in both cases, possibly through nonintentional but foreseeable events (Monterroso 2005, Rodriguez-Labajos 2006).

Perfect Aquatic Invasives: Characteristics of D. polymorpha and H. verticillata

The zebra mussel is a bivalve mollusk belonging to the family Dreissenidae, with a triangular shell reaching up to 50 mm. It occurs in freshwater habitats such as estuaries, rivers, and lakes at temperatures ranging between 12°C and 20°C but it can survive between 0 and 30°C (Olenin and others 1999).

During the last 200 years, the zebra mussel has spread around Europe (Karatayev and others 1997) and in the mid 1980s, the species reached North America, where it colonized the Great Lakes and extended through the Mississippi River down to the Gulf of Mexico (Minchin and others 2002). The large distribution of this species is a result of its highly reproductive capability—a mature female produces one million individuals per year—and its ability to survive out of the water for several days (Olenin and others 1999). The most important pathways for its spread are shipping activities (ballast water, hull fouling) and the creation of invasion corridors such as canals (Carlton 1996, Kraft and others 2002, Minchin and Golash 2002). Its main impacts are related to two distinctive features: removing planktonic organisms and particulate matter by filtering water and attaching to solid surfaces in very high densities (Johnson and Padilla 1996). Pipes and other infrastructures can be seriously damaged, causing important economic impacts (Pimentel and others 2005).

The second species studied is hydrilla, an aquatic plant belonging to the family Hydrocharitaceae. Hydrilla is a fast-growing plant well adapted to a wide range of limnological conditions because of its polymorphic features and metabolism (Langeland 1996). It can live at a depth of 7 m with a growth rate of 5 to 10 cm daily. It spreads by fragments, rhizomes, turions, and seeds (Arrivillaga 2002). This plant can resist some days outside water. Turions can survive several years buried in sediments.

Hydrilla was first introduced from Southeast Asia into North America via aquarium trade, where it was cultured and sold as an ornamental plant in the late 1950s. It spread rapidly in the natural waterways of the southern United States during the 1960s and 1970s. Despite the halting of its commercial sale by the U.S. government in the 1980s, it continued spreading. In Central America, hydrilla was first found in Lake Gatun in Panama, in the 1970s. It became an agricultural problem in the 1980s in Mexico (Haller 2002).

Characteristics of the Invaded Ecosystems

Both cases occur in environmentally rich ecosystems in regions with a history of isolation from political centers. Hydrological resources in these areas are important for subsistence activities as well as for industrial economic interests.

The Ebro case came into the open in 2001 when local residents found some specimens of zebra mussel. A local environmentalist group alerted the relevant authorities. A first study monitoring its presence in the Ebro revealed that colonization of this species was affecting an area of 40 km in the south part of this region (Grup de Natura Freixe and Jiménez Ruiz 2002). Recently, the presence of zebra mussel was detected in the Sobron reservoir, in the headwaters of the Ebro (CHE 2006). The invaded area under study is located in the lower part of the Ebro River, 60 km from the Delta. It belongs to two autonomous regions of

Spain: Aragon and Catalonia. By the middle 1960s, three dams (Mequinensa, Riba-roja, and Flix, all of them now affected by the presence of zebra mussels) were built as hydroelectric power plants, dramatically changing the way of living of many of the flooded village inhabitants.

By 1985, the Ascó nuclear plants (2000 MW) started their activity some kilometers to the south. Close to Ascó in Flix, highly polluted loads coming from the chemical factory, Erkimia, have been regularly dumped into the reservoir (Grimalt and others 2003). The region has also experienced intense social protests in the last several years against the intended plan to transfer water from the Ebro to southeast of Spain.

The main economic activities in the area are agriculture (fruit trees in the irrigated area; olive and almond trees and vineyards in the dry one), pig and poultry breeding, industry (energy and chemicals), and services, especially tourism. Since the late 1970s, tourist activities have grown in importance, related to sport-fishing. Anglers from Europe arrive in the area for fishing wels catfish (*Silurus glanis*), carp (*Cyprinus carpio*), or black-bass (*Micropterus salmoides*). Local environmental authorities estimate that 70% of all the fish species that can be found in the area are non-native. One plausible hypothesis for the arrival of zebra mussel in the area is that larvae were brought in the water where living baits are transported. Other pathways could have been boats or anchors.

Despite water pollution and the changes along the river course, the Ebro is still the habitat for many aquatic species, including endangered species such as the bivalve *Margaritifera auricularia.* Natural habitats include Mediterranean bushes and some woods of white pine (*Pinus halepensis*). Along the riverbank, other vegetal communities such as reedbeds and poplar forests give shelter to a remarkable abundance of local and migratory birds. For this reason, some areas are already protected and some others are proposed as Natura 2000 sites.

The second case takes place in Lake Izabal, the largest freshwater ecosystem in Guatemala. The lake is more than 700 km^2. It drains to the Caribbean Sea. In 2000, local residents reported the outgrowth of an aquatic plant. Early analysis revealed the presence of hydrilla covering over 21 km^2 (Haller 2002). Izabal watershed includes both freshwater and marine ecosystems. It represents an important tourist and commercial site. The lake outlet to the east is a heavily populated tourist area, Rio Dulce, widening into the Caribbean Sea. Along its shores are 19 urban centers with more than 800,000 inhabitants belonging to the q'ekchi Mayan indigenous group and ladino[1] communities (Segeplan 2003).

The region has experienced a history of oppression that deepened during the Civil War (1960–1996), and continued because of mining activities (Cuffe 2005). Lake Izabal has been an important navigation route for export products, mainly coffee, until roads were built in 2001. Although commercial transport is no longer a relevant activity, there are communities that can only be reached by boat. Tourism has become an important activity, attracting international visitors who bring their boats and anchor in marinas located around the lake. Other important economic activities are commercial crops (banana and African palm), cattle raising, and fishing (commercial and sport).

International companies conducted open cast mining 20 years ago. The corrupt process that gave rise to the National Law of Mining (1983), resulted in the deaths of civic leaders and members of parliament (Cuffe 2005). This activity was given up for more than twenty years (nickel prices went down in the mid 1980s). It is now re-emerging in the midst of social protests. Environmentalist groups and local settlers have emphasized the effects of mining on the water quality and on the lake ecosystem in general.

Haller (2002) dates the first appearance of *H. verticillata* in Guatemala further back to 1990, found in isolated ponds. It has been argued that its introduction in Lake Izabal was primarily caused by Hurricane Mitch in 1998 (Haller 2002). Other hypotheses point to an accidental introduction via tourist boat activities or inappropriate aquarium disposals. Protection of the Lake is relevant for conservation purposes because there are different endangered species that inhabit the east shore, including manatees (*Trichechus manatus*) and crocodiles (*Crocodylus moreletti*) as well as several endemic aquatic birds. Efforts to preserve these ecosystems include the creation of a wildlife refuge listed on the Ramsar Convention on Wetlands of International Importance. This wetland area is co-managed by environmental nongovernmental organizations (NGOs), national universities, and the National Council of Protected Areas.

Results

Stakeholders and Their Positions

This section aims to analyze the stakeholders' perceptions of the invasion processes as an environmental problem. From the review of the institutional context, the following configuration of stakeholders can be presented (Table 1).

In both study cases, several administrations (local and regional) have competences in the area. On the one hand, municipalities are responsible for urban planning, whereas most of the decisions regarding environmental policies are made at the regional level. Additionally, there is a specific

[1] Ladino is equivalent to mestizo.

Table 1 List of stakeholders and description of their activities

Stakeholders	*D. polymorpha*—Ebro River	*H. verticillata*—Lake Izabal
Administrations	Different administrations have competences on the area: the Catalan and Aragon governments, municipalities (they have competences on water quality controls, urbanism, and tourism activities) and the Ebro Hydrographical Confederation (CHE), a supraregional entity in charge of the watershed management	Three municipalities have jurisdiction in the lake. Moreover, AMASURLI, the Authority for Sustainable Management of Rio Dulce Watershed has direct jurisdiction for water quality and waste management. A military naval base controls transport of goods in boats
Environmental organizations	Grup de Natura Freixe is a local conservationist group that manages the Natural Reserve for the Wild Fauna of Sebes and Flix meander. It was the first organization to report presence of *Dreissena polymorpha*	Defensores de la Naturaleza co-manages the protected area, including the wetland. Asociación Amigos del Lago is also involved in tourism. Eco-Río was the first formal organization to report presence of *Hydrilla*
Fishing associations	Various fishing associations are in charge of issuing fishing permits. They organize national and international angling competitions	Traditional fishermen are organized in three associations
Tourism organizations	Several marinas and camping facilities rent boats and angling gear and sell tourism packages	There are local tourist committees as well as tourist organizations including marinas
Water transport organizations	—	Lancheros, owners of public and tourist transport boats, are organized in water transport organizations.
Agro industry	Several irrigation communities	There are three important agro-industries: banana, African palm, and rice plantations
Energy and mining sector	ENDESA, controls the Ascó nuclear and the hydroelectric power plants	Exmibal (mining concession for >40 years) along with other three companies
Chemical industry	Erkimia, a chemical industry, uses water for production of chlorine and soda, chlorine derivates, chloride solvents and bicalcic phosphate	—
Subsistence agriculture	—	Represented by women and indigenous organizations

Source: Modified from Binimelis and others 2005

body at the watershed level in both study areas, with jurisdiction for water extraction permits and water quality, and for waste management. In the Ebro, the Hydrographical Confederation is viewed by municipalities as an organization linked to the energy and chemical industry and agrobusiness interests. Its position regarding zebra mussel would favor management alternatives with cheaper economic consequences for these sectors.

In the case of Izabal, the water authority (AMASURLI, acronym in Spanish for Authority for the Sustainable Management of Rio Dulce Watershed) is the regional organization in charge of coordinating activities with the three municipalities that have jurisdiction in the lake. It is a governmental organization that, despite being linked directly to the Secretary of Presidency, lacks human resources and the financial support necessary to establish successful coordination and management of hydrilla. The role of AMASURLI as a regional organization in charge of coordinating and regulating tourism, transport, and monitoring in the lake is not recognized by all the other stakeholders in the lake.

NGOs have no formal role in the design of policies, although they help in implementing policy measures if asked or allowed to do so by the administrations. Thus, the environmental organization co-managing the Ramsar area in Lake Izabal has direct competence in managing hydrilla. In both cases, environmental organizations first translated local awareness and concerns to the government. Moreover, they have been monitoring and providing information to other stakeholders regarding impacts and possible actions to avoid further spread. In fact, environmental organizations have been crucial in focusing public attention on the invasive species and highlighting the environmental impacts they cause. In both cases, environmentalists have used the presence of invasive species as an indicator of ongoing ecosystem degradation.

It is important to notice that there are economic losses in both cases. The most direct economic losses in the Ebro have been related to water uptake facilities and the energy sector, whereas hydrilla has mainly affected tourism and navigation. Stakeholders have opted for technical solutions that temporarily ameliorate the problem. Some of these social actors are still reluctant to apply severe control measures. Such is the case of marinas and angling camps in the Ebro River. They experience constant colonization of their water pipes by zebra mussels but oppose management alternatives that interfere with their tourism activities.

However, in the long run, the zebra mussel invasion might cause bad publicity for the angling industry.

Another example is the agro-industry plantations and transport associations in Lake Izabal that oppose alternatives that constraint their activities, because the hydrilla's impact on their facilities is minor. The relationship of some stakeholders to the invasion can be ambivalent, because they perceive some impacts but at the same time, their practices have probably influenced the level of spread. For instance, the use of fertilizers in plantations of agro-export products in Lake Izabal increases the level of nutrients that can accelerate the reproduction of hydrilla. The movement of boats between reservoirs in the Ebro, which is promoted by marinas, favors the spread of zebra mussel.

Different publicly and privately funded scientific groups have conducted research activities in each region. These different research groups are associated with the stakeholders listed in Table 1; therefore, they were not included as separate groups. Private sector actors have been highly active in the Ebro promoting involvement of different research teams, focusing on the development of systems to protect their own facilities from zebra mussel negative effects. Government organizations have guided all studies on the effects of hydrilla in Guatemala, prioritizing those management alternatives that restore affected socio-economic activities.

Fishing associations have not been active in research or in promoting any form of management in either case. Nonetheless, their participation is relevant because fishing is an important vector of spread. Efforts to establish a commission that integrates and represents stakeholders from both public and private sectors have been launched in the Ebro River and Lake Izabal. However, interviews and participatory workshops have revealed a clash of interests that has made coordinated initiatives more difficult.

Multidimensional Effects of Biological Invasions: Characterization of Impacts

Despite the existence of various studies on the zebra mussel invasion in the Ebro River and hydrilla in Lake Izabal, the socio-economic impacts have scarcely been researched (Aragon Government 2004, Grup de Natura Freixe and Jiménez Ruiz 2002, FIPA-AID 2003, Arrivillaga 2002, Haller 2002).

Impacts were ordered using the categories of ecosystem services proposed by the Millennium Ecosystem Assessment (2003). By affecting the ecological processes at the genetic, species, and ecosystems level, biological invasions modify the provision of ecosystem services, defined as ''the conditions and the processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life'' (Daily 1997). Thus, the use of the ecosystem services classification helps to illustrate the human dependence on ecosystem functioning and the impacts that invasive species cause on it (Binimelis and others 2007). Impacts may be consistently classified through four categories, depending on which type of ecosystem service is affected:

1. Supporting services are those necessary for the production of the other categories of ecosystem services;
2. Provisioning services refer to the products obtained from ecosystems, such as food or timber;
3. Regulating services are benefits supplied by self-maintenance properties of ecosystems;
4. Cultural services generate nonmaterial benefits derived from ecosystems.

Thus, the impacts of zebra mussel and hydrilla can be considered as disruptions in the provision of environmental services supplied by the aquatic ecosystems. A fifth category, impacts on human-made capital, has been added in the case of zebra mussel, because damages to infrastructure are high and they cannot be considered directly as loss of benefits obtained from ecosystems. Next, a presentation of these impacts is displayed (Tables 2 and 3). It is based on the analysis of stakeholder interviews and available reports.

Both areas provide water for drinking, industrial and agricultural activities, and the aquatic ecosystems have recreational uses. In both cases, the use of these environmental services has been affected by the invading species. Both species also can have impacts on human health. Zebra mussel and hydrilla are considered to cause the loss of native species through competition and displacement. In the long term, both species can lead to the disruption of ecosystems, resulting in changes to community structures, the altering of phytoplankton communities, and an increase in the presence of macrophytes.

Perceived impacts can be assessed by quantitative and qualitative indicators. Thus, for instance, the effects of zebra mussel on trophic structure may be measured by indicators of phytoplankton density (cell density μg/l) and/or population changes (percentage of juvenile and adult fishes, weight), and the impacts on infrastructure can be disclosed by estimating the number of installed filters or the cost of the installations. Some of these impacts thus can be reduced to monetary values (either as damage costs or abatement costs) but many require other types of qualitative or quantitative indicators.

Definition of Management Options

In both cases, diverse management alternatives have been proposed or developed by the various stakeholders. These management alternatives are classified depending on their final aim as business-as-usual, adaptation, or mitigation

Table 2 Impacts of *Dreissena polymorpha* in Ebro

Disruption	Impact description: damages or remedial measures	Dimension
Supporting services		
Trophic alteration	Zebra mussel can filter 1 L of water per day, retaining phytoplankton	Ecological
Regulating services: benefits obtained from regulation of ecosystem processes		
Water transparency	Increase of transparency due to the filtering capacity of zebra mussel	Ecological
Changes in substrate	Changes in substrate due to accumulation of shell deposits	Ecological
Increased presence of macrophytes	Increase in the presence of macrophytes because the solar light reaches deeper levels	Ecological
Vectors for parasites and diseases	Appearance of cyanobacteria (Phormidium) related to the activity of zebra mussel, the lack of flow, and high temperature	Ecological
Provisioning services: products obtained from ecosystems		
Competition with local species	The endangered species *Margaritifera auriculata*; *Anodonta cygnea*; *Unio elongatulus* are menaced by the zebra mussel	Ecological
Cultural services: recreation and other nonmaterial benefits obtained from ecosystems		
Loss of navigation/angling services	Fishing lines have been cut by the mussels	Economic
	Use of antifouling paintings in boats	Economic/ ecological
	Several cleaning stations for boats had to be built.	Economic
	Boat cleaning rate fee every time anglers enter and leave the reservoir	Economic
Impacts on human made capital (infrastructures)		
Effect in water intake facilities (human consumption)	Cleaning chemical treatment of the water (chlorine)	Economic/social
	Cleaning of the intake tank filters due to the mussel or to the increase of macrophytes (indirect effect)	Economic
	Installation of new suction pump and pipes	Economic
Irrigation systems	Affecting of the pipes and regulation water tanks	Economic
Effects in hydroelectrical power plant	Change of grilles	Economic
	Use of antifouling paints in intake water facilities	Economic
Effects in the refrigeration system of Ascó nuclear plant	Cleaning activities in the tanks: increase of the water temperature	Economic
	Use of antifouling paints	Economic

Based on: Aragon Government 2004, Asociación Nuclear Ascò-Vandellós 2003, Grup de Natura Freixe and Jiménez 2002, Masip and Rofes 2003, and individual and group interviews

activities. The list of proposed or implemented actions in the two study cases is shown in Table 4. Contents of the table derive from stakeholders' interviews and workshops and the analysis of available reports (Aragon Government 2004, Palau and others 2003, FIPA-AID 2003).

The business-as-usual alternative means in this case that no action is taken by the administrations or any other social actor to control the species. In the study cases, no stakeholder pointed explicitly to this alternative, but they would support it if the implemented alternatives damaged their interests.

The objective of adaptation actions would be to reduce the impacts of introduction, establishment, and spread. The emphasis is put on reducing the costs of the effects of the invasion rather than influencing its likelihood (Perrings 2005). In the Ebro case, this strategy would include general measures such as the information campaign conducted by the Aragon Government. This consists of informative posters explaining the consequences of zebra mussel invasion and the measures for its prevention. Other measures include steam disinfections of boats before and after being used in the area. Adaptation actions would include the private management system established by the Ascó nuclear plant, which heats the water to 38°C before entering the power station, the protection of pipes by filters or floating barriers, and the use of anti-fouling paints in order to prevent the attachment of mussels to boats and grilles (Asociación Nuclear Ascó-Vandellós 2003). In Lake Izabal, an information campaign was also launched by the local authorities together with environmental organizations (FIPA-AID 2003).

Mitigation focuses on actions before or after the initial event of invasion by attempting to reduce both the invasiveness of the species and the invasibility of the ecosystem. Because both cases are ex-post, attempts at eradication and control become examples of mitigation actions, as defined by Perrings (2005). This approach places attention on the driving forces that allow the event to

Table 3 Impacts of *Hydrilla verticillata* in Lake Izabal

Disruption	Impact description	Dimension
Regulating services: benefits obtained from regulation of ecosystem processes		
Water transparency	Large amounts of hydrilla lower sediment resuspension and reduce phytoplankton by compartmentalizing nutrients	Ecological
Changes in substrate	Hydrilla changes soil substrates of lake shores by accumulation of organic matter either by the wind or physical removal of the plant	Ecological
Vectors for parasites and diseases	Stagnation of waters may increase mosquito populations associated with dengue and malaria	Social
Injuries	Skin contact from swimming or physical removal of the plant causes skin sores and allergies	Social
Competition with local species	Displacement of native aquatic plant communities as *Pistia stratiotes*, *Chara phoetida*, *Patamogenton sp*., and *Vallisneria sp*., some of them essential in the diet of the endemic manatee	Ecological
Provisioning services: products obtained from ecosystems		
Decrease in fish production	Fishermen are unable to place fishing nets (trammels) where hydrilla is found because the plant gets stuck in the nets	Economic
Suitable living space for fish	Areas where hydrilla is found provide refuge to fish populations away from trawling fishers	Ecological/ economic
Cultural services: non-material benefits obtained from ecosystems		
Fishing	Fishermen have changed traditional fishing sites and techniques (harpoons instead of trammels)	Economic/ social
Navigation/recreational	Hydrilla obstructs water courses and impedes water access to communities in distant areas of the lake	Social
	Interferes with navigation of commercial and traditional craft as it gets stuck in the engines of larger boats and only small vessels can go through, requiring constant untangling of the plant	Economic
	Increases cost of navigation fees due to higher use of fuel to pass areas where the plant grows	Economic

Based on: Arrivillaga 2002, FIPA-AID 2003, Haller 2002, Langeland 1996, and individual and group interviews

happen. In the Ebro case, three measures have been suggested. On the one hand, emptying the Riba-roja reservoir and thus lowering the water level for a few weeks would expose larvae and adults to air. This would be totally impractical for the very large Mequinensa reservoir. As an alternative, a pilot test was conducted by the army, assessing the feasibility of vacuum cleaning the zebra mussels. The inspection and regulation of boat access at Spanish or regional borders have also been suggested. Chemical control is likely to be proposed (Rodríguez-Labajos 2006). Notice that some actions may at the same time be considered as mitigation and adaptation measures, depending on the scale. Such is the case of the boat disinfection system, which locally helps to protect the boats but also aims to avoid the spread of the species to other water bodies.

For the control of hydrilla in Izabal, mechanical, biological, and chemical means have been used. Mechanical control consists of the physical removal of the plant by cutting or removing. It is divided into mechanized and hand removal. In Izabal, both methods have been used. Local peasants were hired to pull out the plant (up to a depth of 1.5 m) and a machine was used (FIPA-AID 2003). Biological control activities include using pathogens and other herbivorous organisms such as beetles (*Bagous affinis*), flies (*Hydrellia pakistanae*), and carp (*Ctenopharyngodon idella*) (Monterroso 2005). Chemical control is divided into contact and systemic methods. The former includes non-selective herbicides (copper, diquat, or endothall). Systemic methods (fluridone) are supposed to affect only hydrilla. Impacts on other fauna and flora are assumed to be low or nonexistent (Greenfield and others 2004).

Discussion

Human agency is linked to the causes, perception of impacts, and responses to biological invasions. Thus, so as to effectively address invasion processes, it is important to take into account stakeholders' interests and values. This entails bringing into the decision-making process the perspectives of stakeholders by consultation and exchange of information. In this sense, as we have seen, participatory methodologies are a tool for improving the knowledge of the problem. Participation also influences the legitimacy of decisions around the management options.

Table 4 Alternatives for the management of zebra mussel in Ebro River and hydrilla in Lake Izabal

Management alternatives	Status	Proponent stakeholders
Zebra mussel in Ebro River		
Business as usual (do nothing)		
Adaptation actions		
Informative campaign	Implemented	Government of Aragon
Steam disinfection of boats	Implemented partially	Government of Aragon, Ebro Hydrological Confederation
Heating water before enters the refrigeration system in the nuclear power plant	Implemented	Ascò nuclear plant
Engineering solutions for protecting water uptake systems	Implemented	Municipalities, industries, and irrigation communities
Use of anti-fouling paints	Implemented	Boat owners, tourism industry
Mitigation activities		
Borders regulation of boats	Proposed	Group of experts working in other geographical areas
Emptying or lowering Riba-roja reservoir	Proposed	CEPIDE, Ebro Hydrological Confederation
Vacuum cleaning	Testing	Ebro Hydrological Confederation
Hydrilla in Lake Izabal		
Business as usual		
Adaptation actions		
Informative campaign	Implemented	Municipalities, Watershed Authority (AMASURLI)
Mitigation activities		
Physical removal control		
Mechanized	Implemented	AMASURLI
By hand	Implemented	AMASURLI, tourism organizations
Biological control		
Pathogens	Proposed	AMASURLI
Herbivores	Proposed	AMASURLI
Chemical control		
Contact	Testing	Private owners of marinas, AMASURLI
Systemic	Testing	Private owners of marinas, AMASURLI

Based on: Aragon Government 2004; Palau and others 2003; FIPA-AID 2003; and individual and group interviews

Additionally, as we have seen, the social analysis of stakeholders has implications in terms of establishing the boundaries of the system as well as the chosen scale when assessing drivers, causes, and responses to invasive species. The scale of analysis is a determinant cross-cutting issue for all the steps in the invasion processes. This is due to different reasons. First, pathways seem to be related to motions outside the region in both study cases, via the external movement of boats. Second, because these invasions take place in watersheds, both the perception of the impacts and the management strategies involve different scales: site, municipality, watershed, and regional administrations. Tied to every geographic scale there are different suitable indicators of the effects and a specific configuration of stakeholders. Elements from all scales should play a role in any initiative toward the invasion. Taking this into account, definition of the response to the invasion should take place through a participatory multiscale multi-stakeholder exercise. Thus, an open deliberation would avoid reductionism and would disclose the power relations.

Interdisciplinary approaches will allow the emergence of different aspects, depending on the focus of analysis. When analyzing the drivers of the invasion through participatory methodologies (focus groups, in-depth interviews), it was noted that stakeholders link the phenomena of invasions to multiple causes, operating at various scales. In that sense, including stakeholders' perspectives would imply an expansion of the system domain in any long-term management scenario for both study cases. In this regard, it can be appreciated that the topics included in the debate often go beyond the presence of invasive species. The invasion seems to be used to discuss other environmental and socio-economic problems that take place in similar scales involving the same set of stakeholders. Invasions are even used to defend the environment. This is the case of the rejection of the National Hydrological Plan in the Ebro.

The studied sites are affected by other biological invasions besides the described ones. By comparing stakeholders' positions on the presence of different invasive species, it is possible to elicit their working definition of ''invasions.'' In most cases, stakeholders' definition is in concordance with the ''impact approach'' type described in the introduction to this paper. Despite using this common framework, differences are then produced regarding which criteria have to be prioritized. Research results from fieldwork activities indicate that the presence of the Wels catfish (*Silurus glanis*) in the Ebro is described by environmentalist groups as a problem, because it affects the biodiversity of autochthonous species; meanwhile, it is perceived as highly beneficial by municipalities, tourist operators, and fishermen, who highlight its economic benefits.

The vast majority of stakeholders refer to the presence of zebra mussels in the Ebro and hydrilla in Lake Izabal as a pest. This outlook could lead to a consensus on the measures to be implemented. However, this is not the case. Both cases occur in highly politically influenced contexts, with conflicting stakeholder agendas. In the Ebro, during the National Hydrological Plan debate of 2003–2004, the risk of zebra mussel spread was a point raised in Brussels to prevent the European Commission from funding the water transfer. On the other hand, in Lake Izabal local environmental groups have welcomed or at least used hydrilla as a tool to draw attention to the deteriorating condition of the lake caused by mining and agro-industry. Because of experience with previous violent repression, they would rather talk about hydrilla than mining. They brought the bioinvasion case to the International Water Tribunal. The Guatemalan state was accused of negligence with regard to the deterioration of the lake. Invasive species are in theory a common enemy while mining is backed by powerful interests. The underlying wider problem in both cases is not hydrilla or zebra mussels themselves but deciding who controls and uses water resources in the watershed.

Therefore, the way in which the causes and impacts of the invasive species are described would determine management decisions. In fact, officially in both cases the chosen approach has been a technical one, reducing the boundaries of the management scenario to a decision regarding the most effective control option in monetary terms. Consensus of future management scenarios for ecosystems is not pursued; instead, technical measures to manage invasion species are implemented. A broader approach, nonetheless, would take into account watershed management as a possible scenario for managing the invasion process. This would involve participation from social actors trying to fit their own economic and social interests and values to the sustainability of aquatic ecosystems. This is difficult because on the one hand, social actors evidenced disparities in the criteria employed to value the impacts of the invasive species, whereas on the other hand, there are different driving forces exerting pressure on the invaded ecosystem associated with socio-economic and environmental conditions.

Conclusions

This paper compares two ongoing biological invasions to show how the configuration of these phenomena as environmental issues depends on the stakeholders' views on drivers, impacts, and responses. Our focus is the analysis of social conflicts among stakeholders with different interests and values.

In principle, according to the definitions of invasive species analyzed in the introduction, both case studies could be seen as examples of invasions against which stakeholders with different interests and values might fight together against a common enemy. The situation is quite different from an environmental conflict over mining, or over production of chemicals and pollution, where stakeholders are on opposite sides of the economic/environmental divide. Here all stakeholders could prima facie have a common purpose. However, invasions are paradoxically used to defend the environment, as zebra mussels against the National Hydrological Plan or hydrilla against mining activities. Indeed, the discussion has revealed a lack of common purpose. The very definition of invasive species is contested. This is due to the divergence of understanding of different topics:

1. In terms of scale, it is unclear how the boundaries of the system should be defined. The issue includes conflicts on the scale of decision-making, meaning the administrative political level at which management actions should be decided. Scale is also relevant when the origins of the issue have to be recognized, because drivers are characterized by multiple causality.
2. As regards impacts, social actors express their perceptions appealing to different values and languages. Impacts are perceived in different ''units.'' Thus, stakeholders are able to select criteria that do not affect their own interests (e.g., economic revenues). Some actors, such as environmental groups and subsistence agriculture associations, use sets of values pertaining to other nonmonetary dimensions.
3. In both cases, management outcomes do not arise from consensus; instead, partial responses are applied. Management options are also a matter of controversy, because the pros and cons of adaptation and mitigation measures are unequally distributed. Most of the mitigation measures implemented or suggested in both cases do not guarantee success of eradication or even of control, whereas repercussions on different stakeholders remain uncertain and subject to value-laden considerations.

The inclusion of stakeholders in the process of designing, implementing, and monitoring management responses to biological invasions is recommended. However, as we have seen, although the social engagement of stakeholders is necessary in order to foster management actions, it opens up conflicts on the criteria that are relevant, on the scale to be adopted, and on the very definition of invasive species itself.

Acknowledgments The ICTA-UAB group on the socio-economics of biological invasions is funded by FP 6 Integrated Project ''ALARM'' (GOCE-CT-2003-506675). We are grateful to the ALARM socio-economic team, Joan Martinez-Alier, Ines Omman, Joachim Spangenberg, and also Wanda Born and Danny Chivers as well as the ALARM invasive species team for their suggestions and comments on our work. Moreover, we are particularly grateful to local inhabitants and other stakeholders who actively collaborated in the research process.

References

Aragon Government (2004) Against the zebra mussel invasion. Information and environmental education campaign on the zebra mussel invasion in Aragon [in Spanish]. Environmental Department, Zaragoza, pp 60

Arrivillaga A (2002) Evaluación de la presencia de Hydrilla verticillata en la región de Río Dulce y Lago Izabal. Diagnóstico general e identificación de medidas de control. Consejo Nacional de Áreas Protegidas, Guatemala, 30 pp

Asociación Nuclear Ascó–Vandellós (2003) Actuaciones preventivas en la Central Nuclear de Ascó frente a una posible invasión del mejillón cebra: Zaragoza, Asociación Nuclear Ascó–Vandellós–Medi Ambient, Ascó, 14 pp

Binimelis R, Monterroso I, Rodríguez-Labajos B (2005) Assessing ''global invaders''—Two participatory analyses. Paper presented in the 6th International Conference of the European Society for Ecological Economics, Lisbon, June 14–17, 2005

Binimelis R, Born W, Monterroso I, Rodríguez-Labajos B (2007) Biological invasions. In: Nentwig D (ed), Ecological studies 193. Springer-Verlag, Berlin, Heidelberg pp 331–347

Carlton JT (1996) Pattern, process, and prediction in marine invasion ecology. Biol Conserv 78:97–106

CBD (2002) Review of options for the implementation of article 8(h) on alien species that threaten ecosystems, habitats or species. Addendum, use of terms. Sixth Meeting of the International Convention of Biological Diversity. Secretariat of the Convention on Biological Diversity, United Nations Environment Programme

Crosby AW (1986) Ecological imperialism. The biological expansion of Europe, 900–1900. Cambridge University Press, 368 pp (ed. 1993)

Cuffe S (2005) Development upside down. Global stakeholders, mining and community resistance in Honduras and Guatemala [in Spanish]. Derechos en Acción, 50 pp

Daehler CC (2001) Two ways to be an invader, but one is more suitable for ecology. Bull Ecol Soc Am 82:101–102

Daily GC (ed.) (1997) Nature's services. Societal dependence on natural ecosystems. Island Press, Washington, D.C., 412 pp

Dalmazzone S (2000) In: Perrings C, Williamson M, Dalmazzone S (eds.) The economics of biological invasions. Edward Elgar Publishing, Cheltenham pp 17–30

Davis MA, Thompson K (2000) Eight ways to be a colonizer, two ways to be an invader: A proposed nomenclature scheme for invasion ecology. Bull Ecol Soc Am 81:226–230

Davis MA, Thompson K (2001) Invasion terminology: should ecologists define their terms differently than others? No, not if we want to be of any help! Bull Ecol Soc Am 82:206

De Wit MP, Crookes DJ, van Wilgen BW (2001) Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. Biol Invasions 3:167–178

The Ebro Hydrographical Confederation (CHE) (2006) The technical body on zebra mussel would launch a joint strategy with the Environment Ministry for controlling the mollusc spread [in Spanish]. Press release, Zaragoza, 19 September. Available at: http://www.oph.chebro.es/NotasPrensa/18-09-06_01.pdf

FIPA-AID (2003) Environmental impact assessment for the application of control and mitigation measures against the invasive species Hydrilla verticillata in Izabal, Guatemala [in Spanish]. Environmental Ministry, Protected Areas National Council, Guatemala, 120 pp

Giampietro M (2004) Multi-scale integrated analysis of agroecosystems. CRC Press, Washington, D.C., 456 pp

Greenfield BK, David N, Hunt J, Wittman M, Siemering G (2004) Review of alternative aquatic pest control methods for California waters. Aquatic Pesticide Monitoring Program, Oakland, 106 pp

Grimalt JO, Sánchez-Cabeza JA, Palanques A, Catalan J (2003) Study on the dynamics of the organoclorated persistent compounds and other contaminants in the continental aquatic systems [in Catalan]. Catalan Water Agency-Interdepartmental Research and Technology Commission, Barcelona, 254 pp

Grup de Natura Freixe, Jiménez Ruiz PJ (2002) Location and assessment of the zebra mussel (Dreissena polymorpha) biological invasion spread in the Ebro [in Catalan]. Catalan Government, Environment Department, Forest and Biodiversity Directorate, Flix, 56 pp

Haller WT (2002) Hydrilla in Lake Izabal, Guatemala: Current status and future prospects. Report for the USAID-Guatemala. University of Florida, 26 pp

Johnson LE, Padilla DK (1996) Geographic spread of exotic species. Ecological lessons and opportunities from the invasion of the zebra mussel *Dreissena polymorpha.* Biol Conserv 78:23–33

Karatayev AY, Burlakova LE, Padilla DK (1997) The effects of *Dreissena polymorpha* (Pallas) invasion on aquatic communities in Eastern Europe. J Shellfish Res 16:187–203

Kowarik I (2003) Human agency in biological invasions. Secondary releases foster naturalisation and population expansion of alien plant species. Biol Invasions 5:293–312

Kraft CE, Sullivan PJ, Karatayev AY, Burlakova LE, Nekola JC, Johnson LE, Padilla DK (2002) Landscape patterns of an aquatic invader: assessing dispersal extent from spatial distributions. Ecol Applic 12:749–759

Langeland KA (1996) *Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae), ''the perfect aquatic weed.'' Castanea 61:293–304

Levine JM, Montserrat V, D'Antonio C, Dukes JS, Grigulis K, Lavorel S (2003) Mechanisms underlying the impacts of exotic plant invasions. R Soc Rev 270:775–781

Masip M, Rofes J (2003) Localització geogràfica i ecològica de la invasió de *Dreissena polymorpha* en el tram de l'Ebre comprès entre l'embassament de Mequinensa i la desembocadura. Grup de Natura Freixe/Consorci per a la Protecció Integral del Delta de l'Ebre, CPIDE, Flix, 51 pp

McNeely JA, Mooney HA, Neville LE, Schei P, Waage JK (eds.) (2001) A global strategy on invasive alien species. IUCN Gland and Cambridge, x + 50 pp

Millennium Ecosystem Assessment (2003) Ecosystems and human well-being. A framework for assessment. Island Press, Washington, D.C., 264 pp

Minchin D, Lucy F, Sullivan M (2002) Zebra mussel: impacts and spread. In: Leppäkoski E, Gollasch S, Olenin S (eds) Invasive aquatic species of Europe: distribution, impact and management. Kluwer Academic Publishers, Dordrecht 135–146 pp

Minchin D, Gollasch S (2002) Vectors: how exotics get around. In: Leppäkoski E, Gollasch S, Olenin S (eds) Invasive aquatic species of Europe: distribution, impact and management. Kluwer Academic Publishers, Dordrecht pp 183–192

Monterroso I (2005) Comparison of two socio-economic assessment methods for the analysis of the invasion process of *Hydrilla verticillata* in Lake Izabal, Guatemala. Master thesis, Universitat Autònoma de Barcelona, Bellaterra. Available at: http://www.selene.uab.es/brodriguezl

Munda G (2003) Between science and democracy: the role of Social Multi-criteria Evaluation (SMCE). European working group ''Multi-criteria aid for decisions'' 7:1–5

Olenin S, Orlova M, Minchin D (1999) *Dreissena polymorpha*. In: Gollash S, Minchin D, Rosenthal H, Voigt M (eds) Exotics across the ocean. Case studies on introduced species: their general biology, distribution, range expansion and impact. Logos–Department of Fishery Biology, University of Kiel, Kiel 37–42 pp

OTA, Office of Technology Assessment (1993) Harmful non-indigenous species in the United States. OTAF-565. US Government Printing Office, Washington, D.C., 391 pp

Palau A, Cia I, Fargas D, Bardina M, Massuti S (2003) Preliminary results on the basic ecology and spread of zebra mussel in the Riba-Roja reservoir (Ebro river) [in Catalan]. ENDESA, Environment and sustainable development direction, Riba-Roja, 43 pp

Perrings C (2005) Mitigation and adaptation strategies for the control of biological invasions. Ecol Econ 52:315–325

Perrings C, Williamson M, Dalmazzone S (2000) The economics of biological invasions. Edward Elgar, Cheltenham, 249 pp

Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino T, Tsomondof T (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. Agric Ecosyst Envir 84:1–20

Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol Econ 52:273–288

Pyšek P, Richardson DM, Rejmánek M, Webster GL, Williamson M, Kirschner J (2004) Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. Taxon 53:131–143

Rauschmayer F (2003) Integrated assessment of biological invasions as a base for biodiversity policies. Paper presented at BIOECON International Conference on Economic Analysis of Policies for Biodiversity Conservation, 28–29 August 2003, Venice, Italy

Ravetz J (1971) Scientific knowledge and its social problems. Clarendon Press, Oxford, pp 449

Rodríguez-Labajos B (2006) Interlinked biological invasions in the Ebro River. A multi-scale scenario approach. Master thesis, Universitat Autònoma de Barcelona, Bellaterra. Available at: http://www.selene.uab.es/brodriguezl

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, LeRoy Poff N, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. Science 287:1770–1774

Segeplan (2003) Strategy for poverty reduction [in Spanish]. El Estor. Guatemala Government, Guatemala, 54 pp

Shafroth PB, Cleverly JR, Dudley TL, Taylor JP, Van Ripper C III, Weeks EP, Stuart JN (2006) Control of *Tamarix* in the Western United States: implications for water salvage, wildlife use, and riparian restoration. Envir Manage 35:231–246

Shine C, Williams N, Gündling L (2000) A guide to designing legal and institutional frameworks on alien invasive species [in Spanish]. Environmental Policy and Law Paper No. 40. IUCN, Gland, xvi + 162 pp

Shrader-Frechette K (2001) Non-indigenous species and ecological explanation. Biol Philosophy 16:507–519

Simberloff D (2003a) Invasion biology. Crititique of a pseudoscience by D.I. Theodoropoulos [book review]. Ecol Economics 48:360–362

Simberloff D (2003b) Confronting introduced species: a form of xenophobia? Biol Invasions 5:179–192

Strand R (2002) Complexity, ideology, and governance. Emergence 4(1/2):164–183

Theodoropoulos DI (2003) Invasion biology. Critique to a pseudoscience. Avvar Books, Blythe, California, xiv + 237 pp

Vitousek PM, D'Antonio CM, Loope LL, Westbrooks R (1996) Biological invasions as global environmental change. Am Scientist 84:468–478

Vitousek PM, D'Antonio CM, Loope LL, Rejmánek M, Westbrooks R (1997) Introduced species: a significant component of human-caused global change. N Zeal J Ecol 21:1–16

Williamson M (1996) Biological invasions. Chapman and Hall, London, 244 pp

Article 2:

Coexistence of plants and coexistence of farmers: Is an individual choice possible?

Published in Journal of Agricultural and Environmental Ethics

Journal of Agricultural and Environmental Ethics (2008) 21:437–457
DOI 10.1007/s10806-008-9099-4

ROSA BINIMELIS

COEXISTENCE OF PLANTS AND COEXISTENCE OF FARMERS: IS AN INDIVIDUAL CHOICE POSSIBLE?

(Accepted in revised form April 19, 2008)

ABSTRACT. The introduction of genetically modified organisms (GMOs) in Europe has been characterized by controversy. In 2002, the European Union introduced the concept of "coexistence" as a compromise solution that, through the establishment of science-based technical measures, should allow the market to operate freely while reducing policy conflicts on GMOs. However, the concept remains highly contested and the technical measures difficult to apply. This paper presents qualitative research on the conceptualization and implementation of the coexistence framework in two regions of Spain (Catalonia and Aragon), where 42% and 55% of maize was GM in 2006, respectively. In this context, the concept of coexistence and its proposed implementation both fail to resolve previous conflicts and actually work to generate new ones through the individualization of choice and impacts. Considerations of the social conditions in which the technology and the management measures are implemented were not taken into account. This resulted in the promotion of biotechnological agriculture over other alternatives.

KEY WORDS: Coexistence, GMOs, liability, maize, organic agriculture, Spain

1. INTRODUCTION

The use of genetically modified organisms (GMOs) in Europe has generated a variety of policy responses that are under constant development. The concept of coexistence, which was first introduced in 2002 by the European Commission, has become one of the main topics of controversy. With a double objective, this policy framework aimed, on the one hand, to deal with the emerging concerns derived from the admixture between GM, conventional, and organic crops. This issue was especially relevant for organic producers, who are committed to a worldwide consensus not to use GMOs (IFOAM, 2002; Barth et al., 2002). On the other hand, the coexistence concept intended to lift the existing "de-facto" moratorium within the European Union on new commercial agro-food biotechnology applications because, as stated by Franz Fischler, the Commissioner responsible for agriculture, "no form of agriculture should be excluded in the EU" (European Commission, 2003a). As a compromise solution, the establishment of science-based technical measures to ensure coexistence had to allow the market to operate freely, while reducing the policy conflicts on GMOs (Levidow and Boschert, 2007; Rodgers, 2007).

Accordingly, the European Commission issued non-binding guidelines on coexistence in July 2003, to be developed and implemented by the Member States. Coexistence was then defined as ''the ability of farmers to make a practical choice between conventional, organic, and GM crop productions.'' Demarked in the economic sphere, ''co-existence thus concerns only the economic implications of GMO admixture, the measures to achieve sufficient segregation between GM and non-GM production and the costs of such measures'' (European Commission, 2003b). Germany, Denmark, Portugal, and six of the Austrian Länder have adopted the coexistence guidelines into their legislation, while in the majority of other states only draft measures have been issued (European Commission, 2006a). Meanwhile, some Member States are requesting a European legal framework on coexistence, instead of developing National rules (Assembly of European Regions, 2005).

Since the concept was coined, a corpus of literature related to the issue of coexistence has emerged, including research papers, technical reports, and various conference proceedings. On the one hand, most of the studies regarding coexistence have dealt with the technical measures to ensure it. In that sense, the first report on coexistence appeared in 2002, as a summary on a conference organized by the German Federal Environmental Agency (Barth et al., 2002). In the same year, two other official reports were published (Bock et al., 2002; Eastham and Sweet, 2002). In the first, published by the European Environment Agency, the significance of pollen-mediated gene flow from six major crops was assessed. The results of the report showed difficulties to spatially isolate maize, oilseed rape, and sugar beet, advising the implementation of barrier crops, isolation distances, and information systems. The second report, conducted by the EC-Joint Research Centre, was launched after a call in the EC communication ''Life Sciences and Biotechnology – A strategy for Europe'' (European Commission, 2002). One of the main conclusions of this report was that coexistence was feasible but required adjustments in the current farm practices. The results were updated with the analysis of study cases (Messéan et al., 2006). For an overview of the European research on coexistence in the 6th Framework Programme, see European Commission (2006b).

The technical measures for ensuring coexistence have also been studied at the national level by Tolstrup et al. (2003) and Christey and Woodfield (2001), among others. Besides these general reports, agronomic aspects have been covered by using both spatial simulation models (Belcher et al., 2007) and field tests (e.g., for maize, see Henry et al., 2003; Ma et al., 2004; Devos et al., 2005; Messeguer et al., 2006; Bannert and Stamp 2007; Weber et al., 2007;

Langhof et al., 2008). The feasibility of GM crop containment has been discussed by Snow (2002), Haygood et al. (2004), and Marvier and Van Acker (2005), among others. Other technical perspectives include the economic (Smyth et al., 2002; Beckmann et al., 2006) and the liability analysis of coexistence (Koch, 2007; Rodgers, 2007).

On the other hand, a series of authors have highlighted the difficulties – or impossibility – of coexistence between organic and GM-based agriculture due to environmental, food safety, socio-economic, and ethical concerns. A clash of rationales at the technical (Müller, 2003; Altieri, 2005; Ponti, 2005) or conceptual level (Lyson, 2002; Levidow and Boschert, 2007; Verhoog, 2007; McAfee, 2008) is alleged, arguing for the declaration of GMO-free regions (Schermer and Hoppichler, 2004; Jank et al., 2007). In these studies, organic agriculture is usually understood not only in terms of input substitution, but also as a de-intensified and re-localized sustainable development model associated with a peasant and family farming view. This conceptualization has also been named "agroecology," "civic agriculture," or "alternative agriculture," depending on the emphasis or cultural context.

Most of these studies were conducted ex-ante, based on modeling and experimental cases, or were done at the theoretical level due to the lack of commercial fields in most European countries. The objective of this paper is to discuss the concept of coexistence in regard to its objectives: as a policy frame that aims to avoid conflicts by allowing the free market to operate. This is done by analyzing the conceptualization and implementation of "coexistence" in Catalonia and Aragon (NE of Spain) where 23,000 and 35,900 ha of GM maize were planted respectively, during 2007. The results of this unique experience in Europe are especially relevant for the European Commission's assessment of the implementation of coexistence, which will be reviewed during 2008.

The paper is organized as follows. First, I shall explain the methodology used for conducting the study. Next, the research is contextualized by introducing the dynamics of the maize sector in the areas of study. An overview on the legislative proposals at the Spanish and Catalan level to manage the coexistence is also done. The following section analyses how the concept of coexistence is conceived by different stakeholders, and discusses the feasibility and implications of these different conceptualizations, focusing on the technical measures to ensure coexistence and the liability scheme. Finally, the objectives of the coexistence framework are discussed in light of these results.

2. METHODOLOGY

The results presented in this paper are part of on-going research that started in 2002, using discourse analysis and qualitative techniques to elicit stakeholders' points of view and practices. The choice of topic is due to the author's pre-existing interest in the debate on the introduction of agrobiotechnology in Spain, where I have taken part as a research scholar and as a member of the agroecological movement in Catalonia. This involvement, both as an activist and an academic, has allowed me to gain better access to the informants and the information through the fieldwork and literature review. At the same time, this has given me the opportunity to discuss the progress and results of the research in both arenas, and personal involvement has not been too strong to allow fruitful discussions and interviews with stakeholders on all sides of the political lines of conflict. My investigations have been conducted using an action research approach, trying to articulate practical and action-oriented outcomes with reflection on participative, inclusive, and grounded in experience forms of understanding (Reason and Bradbury, 2001). They have been driven by the intention to make visible a situation that is not fully recognized. The research is, on one hand, focused on the analysis of how the admixture of GM with non-GM crops is framed by the different groups of stakeholders. In order to draw out the different frames, I use a discourse analysis approach. This approach has been widely used for analyzing environmental conflicts in general (Hajer, 1995) and also for controversies over biotechnology (Heller, 2002, 2006; Levidow and Boschert, 2007; Levidow and Carr, 2007). Discourse is here defined as a way to understand a shared system of knowledge or belief and the social practices in which it is produced through which meaning is given to the world (Hajer, 1995, p. 44).

On the other hand, the stakeholders' practices and experiences in their daily life are highlighted, not only focusing on their world as "thought," but also as "lived." For doing so, qualitative research techniques were used, by means of group and individual in-depth interviews and participant observation, which also included the attendance at workshops and local and international conferences. Interviews targeted two groups of stakeholders. The first group included 22 farmers (eight farmers sowing both GM and conventional maize, nine cultivating conventional maize, and eight organic farmers), eight technicians or managers of cooperatives in the maize sector and two purchasing managers for starch and glucose companies, which establish their own segregation systems in order to be provided with non-GM maize. The second group was composed of stakeholders related to the debate on coexistence at the policy level. It included 19 semi-structured and three in-depth interviews. Stakeholders were selected among politicians and public administrators, representatives from agricultural unions, consumers' organizations, environmental and development NGOs, biotechnologists and experts on the organic agriculture sector. Thirty-one of the interviews were recorded (with audio or video), transcribed and sent back to participants for review. The rest, 23, were recorded with field notes, as the informants did not wish to be audio recorded. All informants were interviewed in their workplace or house, which included visits to the farmers' fields and cooperatives. The objective was to contextualize the research activities while providing a comfortable environment for those participating in the interviews (Kvale, 1996).

Research involved an interactive play between the qualitative database and the background theory. A literature review compiled European Commission official press releases and communications, legislative documents, papers, and technical reports as well as other types of documents (press releases, statements, pamphlets, and web pages) produced by other stakeholders. Other secondary sources have included results of different research projects, scientific meetings, and round tables conducted at the European and national level.

3. THE MAIZE SECTOR IN CATALONIA AND ARAGON

In spite of the de facto moratoria in other European countries, introduction of GM maize in Spain started in 1998. The available GM varieties have grown from the initial 16 to 61 in 2007. All the current varieties derive from the GM maize event Mon810 modified to be resistant to the corn borer. The rate of farmers' adoption and hectares under GM maize cultivation have arisen according to this increasing number of registered GM maize varieties, although with a very heterogeneous distribution. Data from the Ministry of Agriculture, extrapolated from the seed companies sales, report 75,000 ha of GM maize in 2007 (MAPA, 2007), 14.5% of the total grain maize area.

Around 85% of the maize in Spain is used for feed production (Demont and Tollens, 2004). With an overall production of 5 million tones of maize, Spain also imports around 2 million tones of Brazilian, USA, and Argentinean maize, presumed to largely be GM maize (European Commission, 2005). Moreover, standard feed contains around 20% of soy, 98.7% GM following the estimates of the Ministry of Agriculture. As a consequence, almost all the manufactured feed in Spain is labeled as containing GMOs (Ortega, 2006).

This study was undertaken in Catalonia and Aragon, the areas with the highest concentration of GM maize adoption. This percentage was 55% and 42% in 2006, respectively (Ortega, 2006). In both regions, maize production and the fabrication of feed and fodder are key agricultural activities, mainly related to the meat industry (Badía Roig et al., 2001). Although the area allocated to crops remains stable, the number of holdings is decreasing due to land concentration. Despite this, the average size of farms remains small

(5.45 ha in Catalonia, while in Aragon the average is 7 ha in the case of grain and 30 ha for forage maize) and it is highly fragmented (IAEST, 2007). Prices received by maize farmers have been constant or slightly decreasing during the last 15 years (around 0.13 €/kg) (MAPA, 2007). There is no price differentiation between GM and conventional maize. In the case of organic maize, it is sold by organic farmers at a higher price, 0.21 €/kg (interviews with organic farmers).

The maize production process is integrated in cereal cooperatives, which cover the entire production chain. This vertical integration often includes also the meat production (e.g., in the pig sector). The farmer – called "integrator"– then becomes like a wage-earning worker (Langreo Navarro and González del Barrio, 2007). Cooperatives sell the inputs (seeds, fertilizers, herbicides) and lease the machinery to the farmers and process (e.g., drying) and sell the product. Often they also grant credits to the farmers during the season, which are then subtracted from the money received after the grain is dried in the cooperative (interviews with cooperative managers). Through this process, the manager or technician of the cooperative, who also provides the technical advice, becomes a key actor in the introduction of new technologies at the local level. This structure implies the concentration of infrastructures, which also makes it difficult and expensive to segregate GM production from organic and conventional during the production chain. There are no specific silos for organic maize while only a minority of the cooperatives in the region restrict the use of GMOs.

At the same time, organic agriculture is also in expansion, increasing in the number of producers, manufacturers, and hectares (926,400 ha were reported in 2006 by the Spanish Ministry of Agriculture). Most of the production is exported to other European countries. There are no official data on the surface planted with organic maize. However, a frequently used approximation was made by Brookes and Barfoot (2003), who estimated the area of organic maize in Spain to 1,000 ha. In 2002, the area sown with organic maize in Catalonia and Aragon was 90 and 120 ha, respectively. This area has not grown, for reasons explained in this paper.

4. LEGISLATIVE PROPOSALS FOR COEXISTENCE

Up to four preliminary documents on the implementation of coexistence have been released by the Spanish administrations since 2004. However, they have been highly contested by agrarian and environmental organizations. No agreement has been reached so far. Instead, some guidelines on good practices for cultivating GM maize have been promoted by the seed producers association (APROSE, 2006). In parallel, Catalonia, one of the

Spanish regions with a high degree of autonomy, is developing its own coexistence legislation, although the proposals have yet to be approved. Together with the call to regulate coexistence, the Catalan Parliament (2004) urged the creation of a "GMO-free" quality trademark, but neither has been implemented.

While in some European countries, participatory processes were held before GM crops introduction (Gaskell et al., 2003; Schläpfer, 2007), in Spain the situation was different, and public participation was almost non-existent during their sow in the fields. This could be grounded in the low level of public awareness in relation to environmental problems in Spain, a short tradition of participation and a high scientific and technical optimism (Todt, 1999). However, the discussion has been opened within the framework of negotiations on coexistence legislations. This development was mainly due to environmentalists, farmer associations, and activist groups, with a highly confronting discourse. It seems fair to say that it has been difficult to establish a real, transparent dialogue between the stakeholders.

5. HOW IS COEXISTENCE CONCEIVED AND IMPLEMENTED?

In this section, the conceptualization and implementation of the coexistence framework is analyzed for the case of Catalonia and Aragon. I shall first discuss how the concept of coexistence is conceived by different stakeholders. This is connected to a dissimilar assessment of the potential impacts that should be incorporated in the framework. Following this, the proposed technical measures for coexistence and for the liability and redress scheme are analyzed in terms of feasibility and implications.

5.1. *The Concept of Coexistence*

The analysis of the existing approaches for coexistence in the case study reveals two conflicting rationales. One group of actors attach themselves to the Commissions' definition of coexistence, as the farmers' right to choose the type of crop production (European Commission, 2003a; 2003b). A clear distinction is made between the economic aspects of coexistence and the environmental and health aspects, assuming the latter to be sufficiently addressed by Directive 2001/18/EC. Coexistence is framed as the requirement of some economic agents for maintaining the economic added value of their production (AGPME and EFEagro, 2006). The object of the discussion is then how to design the science-based technical measures to minimize the derived costs of segregation in a proportionate manner at the farm level.

For another group of stakeholders, the concept of coexistence was introduced to force the end of the moratoria, following the exigencies of the

World Trade Organization. This was done by developing a series of technical measures to deal with the introduction of GMOs as a matter of fact, without a discussion of the underlying purpose and bypassing the political conflicts around it. This perspective, shifting the focus from farmers' right to choose to consumers' rights (e.g., European Parliament, 2003), challenges the compatibility of GM with organic agricultural systems and promotes, for instance, the creation of European GMO-free zones or regions. Delimitations between economic, social, environmental, safety, and ethical aspects are blurred. As it will be discussed in the next section, different conceptions of biotechnology and its implications lie behind the two described frames.

5.2. *What is at Stake? The Notion of Genetic Contamination*

The opponents of GM technology consider so-called genetic contamination as a major threat to organic agricultural systems and biodiversity. "Contamination" here refers to the unwanted process that transgenes from GM crops move to other organisms and become established in natural or agricultural ecosystems (McAfee, 2003; Walters, 2004, Binimelis, 2005; Verhoog, 2007). It is argued that this admixture has agronomic, environmental, and socio-economic implications, raising concerns for food safety, consumers' rights or the integrity of organic and conventional agriculture and the seed system. Appealing to the irreversibility of the process, the technology is described as involving a high level of uncertainty.

Although the concept can be applied to admixtures both with organic and conventional crops, the discussion is more vivid regarding organic agriculture, as most organic farmers and consumers reject the presence of GM traces in organic products. There are several reasons behind this. As stated by organic farmers, for many of them, organic agriculture is not only a way of producing, but a way of living, in contrast to intensive agriculture. GM technology is judged as uncertain, and a step forward in the intensification of the agricultural industrial model to the detriment of small farmers and the local control of resources. For instance, an organic farmer in the north of Catalonia decided to burn his harvest after it was found to contain GMOs, refusing to place in the market a product that he considered risky and damaging to local agriculture (organic maize farmer, interview). Another central point of the discussion has been the role played by GMOs in the erosion of agrobiodiversity, especially linked with the non-hybrid varieties. The issue became essential after GM contamination was found in the red-colored non-hybrid variety "embrilla," which had been conserved by an organic farmer in Aragon for 15 years, after it had almost disappeared (Assemblea Pagesa et al., 2006). In Catalonia, contamination was also found in the variety "queixal" in the private Center of Biodiversity

Conservation "Esporus." Moreover, it is argued that the right of organic agriculture to remain GMO-free and the right of organic consumers to choose are seriously compromised. Traceability and labeling are judged as impracticable as GMO contamination grows. To sum up, the arguments are make explicit by the following statement from an interview with an organic farmer: "*Why do we need to have GMOs if this technology creates uncertainties, contamination, homogenizes agrarian cultures, the consequences concerning health effects are not clear enough and there are huge questions related to ethical issues? What do we need them for? If there is a food crisis, why not opt for more sustainable approaches?*"

These arguments confront the discourse of proponents of GMOs, who argue that GMOs do not differ substantially from conventional varieties and, as GM crops undergo a risk assessment process, they have been proven to be even safer than the conventional varieties. There is also a distinction between issues evaluated by the risk assessment process (mainly environmental, human, and animal health) and those aspects that relate to social or ethical concerns, which remain outside the sphere of the decision-making. From that point of view, the concept of contamination should be rejected as tendentious, implying that GMOs are inferior. Indeed, the potential contribution of GMOs to sustainability is highlighted: "*the problem with organic agriculture, its direct confrontation with the biotechnological one is its own positioning for not accepting genetic modifications as valid for its production. However, to have a plant resistant to insects which in the future could be capable of not needing water for irrigation would be the paradigm of organic agriculture*" (biotech company representative, interview). The argument of biodiversity erosion is also challenged: "*We are opening the possibility of biodiversity, we are putting in the hands of farmers many more varieties... the only thing we are doing is, in some varieties, to add resistance to an organism that can destroy them directly. Therefore, the discourse "with the GMOs we are diminishing the biodiversity" is very difficult to explain to us, as we are seeing it, more varieties are grown all the time*" (biotech company representative). The argument of the consumer's right to choose is also used for justifying the introduction of GMOs.

5.3. *Technical Measures for Coexistence*

These divergent approaches to coexistence have emerged throughout the discussion of the technical measures for ensuring it. Such measures were meant by the EC to be cost-effective and proportionate (European Commission, 2003b), but disagreement exists on what the objective is. While for one group the proposed technical measures would mean a disproportionate burden for GMOs, the other group of stakeholders faced a dilemma:

whereas these measures are seen as the ultimate instrument for imposing a non desired agricultural model, the opposition to the coexistence measures leads to a complete lack of regulation of the situation. Accordingly, strategies varied from direct opposition to the coexistence concept, to the request for the strictest measures possible.

Following Regulation (EC) no. 1830/2003, a product has to be labeled as genetically modified if the GM content, assumed to be fortuitous, exceeds 0.9% in any of its ingredients. This practical threshold is established as a convention, so that no economic loss should be suffered by the organic or conventional farmer in case of an accidental admixture. The thresholds for the presence of GM material in seeds have not been established. The labeling norm is seen by proponents of biotechnology and conventional farmers and technicians as a safety buffer to ensure coexistence and minimize derived economic costs. On the contrary, organic farmers and consumers in Spain defend the integrity of organic products as 100% GMO-free – or below the detection level – for the final consumer, even the Council of Agriculture Ministers has recently voted for allowing the same adventitious threshold in organic than conventional products (0.9%) (European Commission, 2007). In that sense, it is stated that if the norms for ensuring coexistence are designed at aiming to achieve a 0.9% threshold, this will become not an accidental threshold but a normal one. There is also a questioning of the cost and significance of this threshold. If GMOs are framed as a technology with uncertain outcomes, what is the difference between 0.9% and 1 or 0.8%?

This discussion links with the debate on the objective of the technical measures. Is it to procure an admixture as low as possible? Or is it to achieve a level that reduces economic costs of admixture? Although the admixture can be produced at the different steps of the production chain (European Commission, 2001), and the draft legislation considers a series of measures (e.g., crop planning or pollen traps) in this paper I will focus on the debate on isolation distances, as they have received most attention. Only one of the informants, a farmer who grows GMOs, negated the possibility of pollen transfer between GM and conventional and organic fields. All the rest accept that this transfer is produced in natural conditions as a matter of fact.

The proposed legislation for coexistence in Spain has gone through the incorporation of various different isolation distances for the case of maize. While in the first drafts, isolation distances were settled at 25 m aiming at not exceeding 0.9% of admixture, social opposition provoked the extension of the prescriptive distances up to 50 m in the last proposal in Catalonia. Meanwhile, the draft legislation for coexistence from the Spanish government suggested the isolation distance at 200 m. However, this is still disliked by many of the stakeholders. As stated above, some push for returning to smaller isolation distances. On the other side, the opponents of GMOs approve of the increased distances, although they still believe them to be insufficient, especially if the aim is to minimize admixture. Proposals range from 500–800 m (main agrarian union) to km (organic farmers and technicians following the rules for plant breeding). Consistent with the two positions, a literature review reveals that recommended isolation distances for maize vary from 25 m up to 10 km, depending on the author and the final admixture threshold permitted (Barth et al., 2002; Müller, 2003; Devos et al., 2005; Messeguer et al., 2006; van de Wiel and Lotz, 2006; Bannert and Stamp, 2007).

The feasibility of implementing isolation distances in the regions, where the size of the plots is small, is also discussed by stakeholders, especially in Catalonia. In this respect, some of the informants see the creation of either GM or conventional and organic homogeneous regions as the only way for observing the rule. This would mean that farmers at a regional scale would need to agree and decide jointly the type of agriculture to be developed, creating a buffer zone around the area to prevent contamination [the strategy is also known as ‘‘landscape clubs’’ (Furtan et al., 2007)]. This is to some extent already happening, since, for instance, starch and glucose companies only buy maize in large areas, often outside the two studied regions, where farmers agree to not using GMOs. These voluntary agreements are, in fact, recommended by the EC guidelines on coexistence. The implications of these agreements, which are also necessary for other proposed measures such as crop planning to avoid flowering coincidence or segregation in later steps of production, will be discussed in the next section.

5.4. *The Social Dimensions of Liability*

Several challenges arise from a forensic view of liability in case admixture takes place, from the quantification of costs and damages to the practical aspects for claiming compensation. In this section, I will analyze the implications of the liability frame regarded in the coexistence proposals.

As discussed above, the coexistence project is constrained within the economic aspects derived from the admixture of GM and non-GM crops. In that sense, only economic damages are addressed by the framework, especially focusing on the variations in economic profit due to the impact of labeling obligation. Other socio-economic non-marketable goods, more difficult to quantify or incommensurable, such as the loss of trust among consumers [as proposed by the European Parliament (2003)] or the admixture of GM maize with a local variety, are not included. By doing so, liability is focused on the individual economic aspects of the issue, while individual and collective concerns at a social and environmental level are left aside.[1]

The trend toward individualization of the liability and redress scheme is also promoted by the coexistence framework regarding the resolution of disputes. In Spain, for instance, individual affected farmers suing for compensation would be obliged to identify the farmer responsible for the contamination and to prove their culpability and the resulting damage, following civil law. Actually, when the first cases of unwanted admixture were reported, it was seen that the whole process was hampered by technical difficulties. Pollen dispersal declines exponentially with distance from source, but often has long "tails" showing that low levels of pollen can disperse over long distances, which might be of concern in case of zero tolerance for organic growers.

Concentration of pollen is then a function of distance but dispersal is not uniform. As the figure depends on the size of the field, measurement of admixture has been heavily contested, especially in the absence of a consensus sampling protocol. Other technical difficulties for the quantification of the content of GM material in on-farm samples cannot be disregarded (Devos et al., 2005). The point can be clearly illustrated by the case that occurred in 2006 in the north of Catalonia, in which an organic maize was found to have up to 12.6% of GM material. This first analysis, performed by the organic production certification body was then contrasted by two other analyses by the Catalan agriculture department and a farmers' union resulting in 0.9% and 6%, respectively (public administrator, interview). In view of such disparate results, some stakeholders have accused the farmer of setting up a farce (biotechnologist, interview). Other cases resulted in positive or negative results depending on the sampling and/or the analytical method. The small size of the farms brings along other technical constraints, as it is not easy to establish direct causality, especially if the rate of GM adoption is high in a region. As a consequence, the affected farmers would have to sue all the neighbors who are potentially able to cause the admixture. A prerequisite for claiming this causality is that farmers, who do not grow GMOs, have at their disposal the information on where GM crops are sown. Although legally since 2006 this information must be stated when filling the CAP declaration, the information is not publicly available. In case

[1] The European Environmental Liability Directive (2004/35/CE), includes remediation at the polluter's expense for environmental and biodiversity damage arising from GMOs releases. However, it has several limitations for the application to cases of admixture between GM and non-GM crops. Activities that were not considered harmful when released or have been authorized are exempt from liability (Khoury and Smyth, 2007; Rodgers, 2007).

the neighbors have observed the prescribed measures, it is not clear who will bear the responsibility.

On the other hand, fieldwork has highlighted that social conditions can become critical in order to establish working liability frameworks. For analyzing that aspect, it is important to understand the conditions in which the technology has been introduced and how it has been done. Most interviewed stakeholders agree when listing the reasons behind the introduction of GMOs in Spain, in spite of the de facto moratoria operating in the other European countries. The main explanation is the political alliance of the former right-wing Aznar government (1996–2003) with the neoliberal governments in the United States and United Kingdom by the time that GMOs were first introduced. Other related explanations are the permissive character of the Spanish administration, the power of agribusiness companies, which in fact are in charge of rural extension, and a low environmental awareness compared to other European countries, which impeded a social debate on the issue.

In regard to the adoption of GMOs, farmers growing them highlight the advantages of this technology for the farm management. It is in a way compared to having insurance, as the farmer can be sure that less grain will be left in the field because the borer will not break or bend the plants. Moreover, most of the stakeholders point out big pressures from the seed companies to introduce and promote GMOs. Public support for rural technological transfer has been diminished in recent years, leaving most of the load to private companies. Agribusiness companies are, in fact, either directly or indirectly through the cooperative technicians, recognized as the leaders of rural extension.

This social pressure for introducing biotechnology, however, does not only come from the companies. Modernization is considered a driver for economic progress and being an entrepreneur is a shared social value. It can be illustrated by a statement from a farmer growing GMOs, who was initially reluctant to do it: "*In the town most of the people say good things [about GMOS], they do not speak badly, on the contrary. They said I was stupid for not planting GMOs in the last two years*." This preference towards modernization and technification was also shared by a cooperative technician, when explaining the change in the use of GM varieties: "*Pioneer is now selling the most because the Syngenta gene is old and people always want the latest [technology]*."

The tension between the productivist agricultural model and a more environmental farming practice is framed as a traditional confrontation between ecologists and farmers in Spain, which remains and is more polarized in areas with intensive farming, as in the area of study. A similar conclusion was reached by Hoggart and Paniagua (2001), who have documented the resistance towards a more environmentally friendly agriculture in Spain in favor of intensification, backed by a lack of agro-environmental legislation until recently (Paniagua, 2001). Organic farming is a locally marginalized agriculture. In that sense, lack of social support becomes the main obstacle for young farmers who want to practice organic agriculture, especially those coming from a rural background (interviews with organic farmers). Organic farming is, for some farmers, a shameful practice, as can be glimpsed in the statement made by a farmer growing conventional maize when explaining his intentions to plant organic maize: "*I will sow organic maize next year but in a hidden plot where nobody sees me, otherwise they will laugh at me*" (interview). Another illustrative example links with the perception of nature and ecosystem functioning and the role played by the farmer. During the field visits, farmers growing GMOs repeatedly referred to the ones growing organic as careless, dirty, and untidy because weeds can easily be seen in their fields. A completely different position is held by organic farmers, who perceive the use of synthetic herbicides as highly polluting, and, therefore, as a negligent practice.

This situation and the way in which GM technology is introduced are critical elements shaping the cases of disagreements among farmers. On the one hand, disagreement exists in regard to the responsibilities of farmers sowing GMOs. These are presented as relying on the technicians and on a product that has been authorized. On the other hand, the liability scheme is perceived as transferring the problem to the organic farmers. As a result, many farmers are reluctant to publicly report cases of contamination in a context where there is a need for social cohesion, as in small villages. One organic farmer said: "*as a consequence of social pressure, when farmers suffer contamination, they do not want to say so. Last year there were 4 contamination cases and 2 made it public but 2 did not. For fear of confronting the people in the town... so they have to assume the economic cost, the environmental cost, and the cost of losing the organic certification but they do not say so*" (interview). Consequently, data on admixture cases are not systematically registered, although the organic certification is withdrawn in these cases. This was the situation in Aragon in 2004, when all the analyzed samples (representing around 200 ha) gave a positive result for presence of GMOs. Moreover, many organic farmers growing maize have already shifted the crop as they wish to avoid direct confrontations with their neighbors: "*I would never do this [bring a neighbor into court]. My neighbor is not my enemy. He is my colleague, from the school, we did communion together (...) We are a small community and we have a community life. He is my friend. I cannot say anything. He is trying to survive and he does what he can. I prefer to give up with agriculture than having bad relations*" (interview).

As a result, from 2004 (when the first analyses were done) to 2007, the area devoted to organic maize was reduced by 75% in Aragon (organic certification body representative, interview). For the case of Catalonia, the surface decreased by 5% from 2002 to 2005 (Morán, 2006). The trend was confirmed by the organic certification body for the following years. Informants within the organic sector have corroborated the difficulty in obtaining local organic maize. In spite of this, some other stakeholders stated that no problem has been observed after 8 years of GM agriculture (AGPME and EFEagro, 2006).[2]

6. DISCUSSION

The conflicts that have arisen from agricultural biotechnology in Europe can be seen as a struggle between confronting frames of interpretation. Against this background, the coexistence concept was introduced as a compromise solution to handle the introduction of GMOs in Europe by way of the implementation of technical measures based on purported scientific criteria (European Commission, 2003b). In the case of Spain, it is worth noting that this aspect was emphasized in the Catalan proposals as "strictly scientific criteria." By doing so, the problem is demarked as a technological fix, in which the ethical, social, political, and environmental aspects are reduced to a quantitative "objective" regulatory setting, which can be managed without the participation of those primarily affected. However, quantification is also a form of making decisions (Porter, 1995). Moreover, the mainstream frame excludes other rationales and criteria, such as food quality, farmer autonomy, or the integrity of organic agriculture (Heller, 2002) that cannot be easily quantified. The specific coexistence proposals in Spain are thus favoring some agendas over others, confirming suspicions in the context of other European countries by Levidow and Boschert (2007). Moreover, science is presented as an autonomous entity of society, objective and neutral, but also as a homogeneous body. These concepts have been widely discussed for the case of agricultural biotechnology, covering issues such as the lay-expert divide in the perception and management of risks (Wynne, 2001), the failure of the science-based risk-assessment procedure to incorporate societal concerns (Carr and Levidow, 2000; McAfee, 2003; Sarewitz, 2004) and the legitimacy of science-based regulations (Levidow and Marris, 2001). A low consensus on the scientific issues and the analytical methods to be applied is also found among scientists (Busch et al., 2004; Myhr, 2005), depending for instance on their work context and background (Kvakkestad et al., 2007).

[2] Isabel García Tejerina, the former Agriculture General Secretary, during the presentation of the National Commission of Biovigilance, declared that "after 6 years of real experience, there has not been any case of contamination" (EFEAgro, 2004), although some official cases had been already published and discussed in the sessions of the National Biosafety Commission (2002), as it is reflected in its proceedings.

The case study shows that these concerns are handled as if they were a matter of private choice, which can be solved (compensated) by market mechanisms. In this case on the one hand, the wider debate on the acceptability or necessity of GMOs is dumped on the individual sphere as if farmers are in charge of deciding what they want to cultivate (Devos et al., 2008). On the other hand, liability based on civil law is focused on monetary compensation, it supports the individualization of the problem and leaving aside social and environmental conditions and effects (McLeod-Kilmurray, 2007). As it has been shown by the fieldwork, it seems that previously unsolved framing conflicts are pervasive in the coexistence concept, while new ones are enhanced. Considerations of the social conditions in which the technology and the management measures are implemented, and to what degree they will be observed, were not taken into account. Problems in establishing causation and dispute-solving mechanisms have resulted in the promotion of a biotechnological agriculture over an organic one.

ACKNOWLEDGMENTS

I wish to thank Roger Strand, Fern Wickson, and Kamilla Kjølberg at the Centre for the Study of the Sciences and the Humanities (SVT) in Bergen, Iliana Monterroso at FLACSO-Guatemala, and Joan Martínez Alier and Nicolas Kosoy at the Autonomous University of Barcelona for their helpful comments on a previous version of this article. The Research Council of Norway and the FP6 project ALARM (GOCECT-2003-506675) have partially funded this research. I am particularly grateful to all the stakeholders who actively collaborated in the research process.

REFERENCES

AGPME and EFEagro (2006), La coexistencia es posible. Jornada técnica. Coexistencia en España de cultivos transgénicos, convencionales y ecológicos. Retos de futuro tras ocho años de convivencia. Retrieved from http://www.antama.net/descargas/informes/informe.pdf on November 15, 2007.

Altieri, M. A. (2005), "The myth of coexistence: Why transgenic crops are not compatible with agroecologically based systems of production." *Bulletin of Science Technology Society*, 25, pp. 361–371.

APROSE (2006), Guía 2006 de buenas prácticas para el cultivo del maíz Bt. Retrieved from www.monsanto.es/Novedad/Folleto%20aprose%202006.pdf on June 7, 2007.

Assemblea Pagesa, Plataforma Transgènics Fora! & Greenpeace (2006), Impossible coexistence. Seven years of GMO's have contaminated organic and conventional maize: An examination of the cases in Catalonia and Aragon, Madrid.

Assembly of European Regions (2005), "GMO – The EU current regulations are far from exhaustive," Strasbourg: Press release, March 24.
Badía Roig, C., P. Sabaté Prats, and M. Ruiz González (2001), "El sector porcino y de la producción de piensos compuestos." in Fundació ciudad de Lleida (ed.), *Anuario 2001*, Lleida: UDL, pp. 17–26.
Bannert, M. and P. Stamp (2007), "Cross-pollination of maize at long distance." *European Journal of Agronomy*, 27, pp. 44–45.
Barth, R., R. Brauner, A. Hermann, R. Hermanowski, J. Meier, K. Nowack, H. Schmidt, and B. Tappeser (2002), Genetic engineering and organic farming. Freiburg/Darmstadt/Berlin, Öko-Institute e.V. Environmental Research Program of the Federal Ministry for the Environment, Nature Conservation and Reactor Safety. Major Issues in Environmental Protection.
Beckmann, V., C. Soregaroli, and J. Wesseler (2006), "Coexistence rules and regulations in the European Union." *American Journal of Agricultural Economics*, 88, pp. 1193–1199.
Belcher, K., J. Nolan, and P. W. B. Phillips (2007), "Genetically modified crops and agricultural landscapes: Spatial patterns of contamination." *Ecological Economics*, 53, pp. 387–401.
Binimelis, R. (2005), *Co-existence of organic and GM agriculture in Catalonia*. MSc Dissertation, Autonomous University of Barcelona.
Bock, A. K., K. Lheureux, M. Libeau-Dulos, H. Nilsagard, and E. Rodríguez Cerezo (2002), Scenarios for co-existence of genetically modified, conventional and organic crops in European agriculture. Joint Research Center.
Brookes, G. and P. Barfoot (2003), Co-existence of GM and non GM crops: Case study of maize grown in Spain (paper presented at the 1st European Conference on the co-existence of genetically modified crops with conventional and organic crops, Slagelse).
Busch, L., R. Grove-White, S. Jasanoff, D. Winickoff, and B. Wynne (2004), Amicus Curiae Brief submitted to the dispute settlement panel of the WTO in the case of EC: Measures affecting the approval and marketing of biotech products.
Carr, S. and L. Levidow (2000), "Exploring the links between science, risk, uncertainty and ethics in regulatory controversies about genetically modified crops." *Journal of Agricultural and Environmental Ethics*, 12, pp. 29–39.
Catalan Parliament (2004), Resolució 172/VII del Parlament de Catalunya, sobre les mesures de determinació dels productes transgènics dins el marc de la qualitat agroalimentària. Catalan Parliament Official Bulletin, 128.
Christey, M. and D. Woodfield (2001), *Coexistence of genetically modified and non-genetically modified crops*. Crop & Food Research Confidential Report, 427. Ministry of Environment, New Zealand.
Demont, M. and E. Tollens (2004), "First impact of biotechnology in the EU: Bt maize adoption in Spain." *Annals of Applied Biology*, 145, pp. 197–207.
Devos, Y., P. Maeseele, D. Reheul, L. Vanspeybroeck, and D. de Waele (2008), "Ethics in the societal debate on genetically modified organisms: A (re)quest for sense and sensibility." *Journal of Agricultural and Environmental Ethics*, 21, pp. 29–61.
Devos, Y., D. Reheul, and A. De Schrijver (2005), "The co-existence between transgenic and non-transgenic maize in the European Union: A focus on pollen flow and cross-fertilization." *Environmental Biosafety Research*, 4, pp. 71–87.

Eastham, K. and J. Sweet (2002), *Genetically modified organisms (GMOs): The significance of gene flow through pollen transfer*. European Environment Agency, 28. Luxembourg, Office for Official Publications of the European Communities.

EFEAgro (2004), El Ministerio de Agricultura, Pesca y Alimentación ofrece a las organizaciones no gubernamentales medioambientales integrarse en la Comisión de Biovigilancia. Retrieved from: http://www.terraagraria.es/front/frameppal.php?idCategoria=1 on June, 2006.

European Commission (2001), Opinion of the scientific committee on plants concerning the adventitious presence of GM seeds in conventional seeds. Health and Consumer Protection Directorate. SCP/GMO-SEED-CONT/002-FINAL.

European Commission (2002), Life sciences and biotechnology – A strategy for Europe. Luxembourg: Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. COM(2002)27 final.

European Commission (2003a), GMOs: Commission addresses GM crop co-existence. Brussels: Press Release, IP/03/314, March 5.

European Commission (2003b), Commission recommendation of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the coexistence of genetically modified crops with conventional and organic farming. Notified under document number C(2003) 2624, (2003/556/EC).

European Commission (2005), Final report of a mission carried out in Spain 07/03/2005 to 11/03/2005 concerning controls on food & feed containing, consisting or produced from GMO, DG(SANCO)/7632/2005-MRFinal Directorate F – Food and Veterinary Office, Health and Consumer Protection Directorate General.

European Commission (2006a), Communication from the commission to the council and the European parliament: Report on the implementation of national measures on the coexistence of genetically modified organisms with conventional and organic farming and Annex. COM(2006)104 final, SEC(2006)313.

European Commission (2006b), GMO coexistence research in European agriculture. Luxembourg, Directorate General for Research – Dissemination and Communication.

European Commission (2007), Organic food: New regulation to foster the further development of Europe's organic food sector. Press release, IP/07/807, June 12, Brussels.

European Parliament (2003), Report on coexistence between genetically modified crops and conventional and organic crops. Committee on Agriculture and Rural Development, 2003/2098(INI).

Furtan, W. H., A. Güzel, and A. S. Weseen (2007), "Landscape clubs: Co-existence of genetically modified and organic crops." *Canadian Journal of Agricultural Economics*, 55, pp. 185–195.

Gaskell, G., N. Allum, M. W. Bauer, L. Jackson, S. Howard, and N. Lindsey (2003), *Ambivalent GM nation? Public attitudes to biotechnology in the UK, 1991–2002*. Life Sciences in European Society Report: London School of Economics and Political Science.

Hajer, M. (1995), *The politics of environmental discourse. Ecological modernization and the policy process*, Oxford: Oxford University Press.

Haygood, R., A. R. Ives, and D. A. Andow (2004), "Population genetics of transgene containment." *Ecology Letters*, 7, pp. 213–220.

Heller, C. (2002), "From scientific risk to paysan savoir-faire: Peasant expertise in the French and global debate over GM crops." *Science as Culture*, 11, pp. 5–37.
Heller, C. (2006), "Post-industrial 'quality agricultural discourse': Techniques of governance and resistance in the French debate over GM crops." *Social Anthropology*, 14 (3), pp. 319–334.
Henry, C., D. Morgan, R. Weekes, R. Daniels, and C. Boffey (2003), Farm scale evaluations of GM crops: Monitoring gene flow from GM crops to non-GM equivalent crops in the vicinity (contract reference EPG 1/5/138). Part I: Forage Maize.
Hoggart, K. and A. Paniagua (2001), "The restructuring of rural Spain." *Journal of Rural Studies*, 17, pp. 63–80.
IAEST (2007), Información estadística de Aragón. Economía/Sector Agrario. EStructura de las explotaciones agrícolas. Retrieved from http://www.portal.aragon.es/pls/portal30/url/folder/IAEST/IAEST_00 on December 4, 2007.
IFOAM (2002), Position on genetic engineering and genetically modified organisms. Retrieved from http://www.ifoam.org/press/positions/ge-position.html on September 4, 2007.
Jank, B., J. Rath, and H. Gaugitsch (2007), "Co-existence of agricultural production systems." *Trends in Biotechnology*, 24 (5), pp. 198–200.
Khoury, L. and S. Smyth (2007), "Reasonable foreseeability and liability in relation to genetically modified organisms." *Bulletin of Science, Technology & Society*, 27 (3), pp. 215–232.
Koch, B. A. (2007). *Liability and compensation schemes for damage resulting from the presence of genetically modified organisms in non-GM crops*. Research Unit for European Tort Law. European Centre of Tort and Insurance Law, Austrian Academy of Sciences.
Kvakkestad, V., F. Gillund, K. A. Kjolberg, and A. Vatn (2007), "Scientists's perspectives on the deliberate release of GM crops." *Environmental Values*, 16 (1), pp. 79–104.
Kvale, S. (1996), *Interviews: An introduction to qualitative research interviewing*, Thousand Oaks: Sage.
Langhof, M., B. Hommel, A. Hüsken, J. Schiemann, P. Wehling, R. Wilhelm, and G. Rühl (2008), "Coexistence in maize: Do nonmaize buffer zones reduce gene flow between maize fields." *Crop Science*, 48, pp. 305–316.
Langreo Navarro, A. and A. González del Barrio (2007), "El sector porcino en España." in UPA and Fundación de Estudios Rurales (eds.), *Agricultura familiar en España 2007*, Madrid: UPA, pp. 228–232.
Levidow, L. and K. Boschert (2007), Coexistence or contradiction? GM crops versus alternative agricultures in Europe. *Geoforum* (in press). DOI 10.1016/j.geoforum.2007.01.001.
Levidow, L. and S. Carr (2007), "GM crops on trial: Technological development as a real-world experiment." *Futures*, 39, pp. 408–431.
Levidow, L. and C. Marris (2001), "Science and governance in Europe: Lessons from the case of agricultural biotechnology." *Science and Public Policy*, 28 (5), pp. 345–360.
Lyson, T. A. (2002), "Advanced agricultural biotechnologies and sustainable agriculture." *Trends in Biotechnology*, 20, pp. 193–196.
Ma, B. L., K. D. Subedi, and L. M. Reid (2004), "Extent of cross-fertilization in maize by pollen from neighboring transgenic hybrids." *Crop Science*, 44, pp. 1273–1282.

MAPA (Spanish Ministry of Agriculture) (2007), Superficie en hectáreas de variedades maíz GM que se encuentran incluidas en el registro de variedades comerciales. Estadísticas semillas de vivero. Retrieved from http://www.mapa.es/es/agricultura/pags/semillas/estadisticas.htm on 15 December.

Marvier, M. and R. C. Van Acker (2005), "Can crop transgenes be kept on a leash." *Frontiers in Ecology and the Environment*, 3, pp. 99–106.

McAfee, K. (2003), "Neoliberalism on the molecular scale. Economic and genetic reductionism in biotechnology battles." *Geoforum*, 34, pp. 203–219.

McAfee, K. (2008), "Beyond techno-science: Transgenic maize in the fight over Mexico's future." *Geoforum*, 39, pp. 148–160.

McLeod-Kilmurray, H. (2007), "Hoffman v. Monsanto: Courts, class actions, and perceptions of the problem of GM drift." *Bulletin of Science Technology Society*, 27, pp. 188–201.

Messéan, A., F. Angevin, M. Gómez-Barbero, Klaus Menrad, and E. Rodríguez Cerezo (2006), *New case studies on the coexistence of GM and non-GM crops in European agriculture*. EUR 22102 EN, 1. 2006. Joint Research Center.

Messeguer, J., G. Peñas, J. Ballester, M. Bas, J. Serra, J. Salvia, M. Palaudelmas, and E. Melé (2006), "Pollen-mediated gene flow in maize in real situations of coexistence." *Plant Biotechnology Journal*, 4, pp. 633–645.

Morán, C. (2006), El maíz transgénico está acabando con los cultivos del ecológico. *El País*, October 19.

Müller, W. (2003), Concepts for coexistence. ECO-RISK, Office of Ecological Risk Reseach, commissioned by the Federal Ministry of Health and Women.

Myhr, A. I. (2005), "Stretched peer-review on unexpected results (GMOs)." *Water Science & Technology*, 52 (6), pp. 99–106.

National Biosafety Comission (2002), Proceedings of the 27th meeting. 27th September, Madrid.

Ortega, J. I. (2006), *La coexistencia de los cultivos modificados genéticamente con los ecológicos* (Paper presented at the VII Congreso de la Sociedad Española de Agricultura Ecológica/III Congreso Iberoamericano de Agroecología. Zaragoza).

Paniagua, Á. (2001), "Agri-environmental policy in Spain. The agenda of socio-political developments at the national, regional and local levels." *Journal of Rural Studies*, 17, pp. 81–97.

Ponti, L. (2005), "Transgenic crops and sustainable agriculture in the European context." *Bulletin of Science Technology Society*, 25, pp. 289–305.

Porter, T. (1995), *Trust in numbers. The pursuit of objectivity in science and public life*, Princeton: Princeton University Press.

Reason, P. and H. Bradbury (eds.), (2001), *Handbook of action research. Participative inquiry and practice*, London: Sage.

Rodgers, C. P. (2007), "Coexistence or conflict? A European perspective on GMOs and the problem of liability." *Bulletin of Science Technology Society*, 27, pp. 233–250.

Sarewitz, D. (2004), "How science makes environmental controversies worse." *Environmental Science & Policy*, 7, pp. 385–403.

Schermer, M. and J. Hoppichler (2004), "GMO and sustainable development in less favoured regions – the need for alternative paths of development." *Journal of Cleaner Production*, 12, pp. 479–489.

Schläpfer, F. (2007), *An analysis of the Swiss vote on the use of genetically modified crops*. Working paper no. 0717. Socioeconomic Institute, University of Zurich.

Smyth, S., G. G. Khachatourians, and P. W. B. Phillips (2002), "Liabilities and economic of transgenic crops." *Nature biotechnology*, 20, pp. 537–541.
Snow, A. A. (2002), "Transgenic crops – why gene flow matters." *Nature biotechnology*, 20, pp. 542.
Todt, O. (1999), "Social decision making on technology and the environment in Spain." *Technology in Society*, 21, pp. 201–216.
Tolstrup, K., S. B. Andersen, B. Boelt, M. Buus, M. Gylling, P. B. Holm, G. Kjellsson, S. Pedersen, H. Østergård, and S. A. Mikkelsen (2003), *Report from the Danish Working Group on the co-existence of genetically modified crops with conventional and organic crops*, DIAS report Plant Production no. 94, Danish Institute of Agricultural Sciences, Tjele.
Van de Wiel, C. C. M. and L. A. P. Lotz (2006), "Outcrossing and coexistence of genetically modified with (genetically) unmodified crops: A case study of the situation in the Netherlands." *Netherlands Journal of Agricultural Science*, 54 (1), pp. 17–35.
Verhoog, H. (2007), "Organic agriculture versus genetic engineering." *Netherlands Journal of Agricultural Science*, 54 (4), pp. 387–400.
Walters, R. (2004), "Criminology and GM food." *British Journal of Criminology*, 44, pp. 151–167.
Weber, W. E., T. Bringezu, I. Broer, J. Eder, and F. Holz (2007), "Coexistence between GM and non-GM maize crops – Tested in 2004 at the Field Scale Level (Erprobungsanbau 2004)." *Journal of Agronomy and Crop Science*, 197, pp. 79–92.
Wynne, B. (2001), "Creating public alienation: Expert cultures of risk and ethics on GMOs." *Science as Culture*, 10 (4), pp. 445–481.

Institute of Environmental Science and Technology (ICTA)
Autonomous University of Barcelona
08193 Barcelona, Spain
E-mail: rosa.binimelis@uab.cat

Article 3:

Catalan agriculture and genetically modified organisms (GMOs) – An application of DPSIR model

Accepted for publication in Ecological Economics

Catalan agriculture and genetically modified organisms (GMOs) - An application of DPSIR model

Binimelis, R.*, Monterroso, I. and Rodríguez-Labajos, B.
Institute of Environmental Science and Technology – Autonomous University of Barcelona

*Corresponing author: rosa.binimelis@uab.cat, rosa.binimelis@gmx.net

Abstract

Although there is a strong controversy regarding the introduction and commercialisation of genetically modified organisms (GMOs) in Europe, GM maize has been sown in Spain since 1998. Stakeholders' positions on the role that GMOs play in trends of the state of agriculture and environment in Catalonia are analysed. The application of the Driving forces –Pressures – State – Impact – Responses (DPSIR) framework in this case study highlights its potential for organising and structuring information. However, the model can be ambiguous when used as an analytical tool in value-laden complex situations. Thus GM agriculture is sometimes seen as a pressure on the agro-environment and sometimes as a modernising response to an economic and environmental crisis. A redefinition of the DPSIR categories is proposed, aiming to reflect on these situations by better acknowledging different legitimate perspectives and narratives. This is done, on the one hand, by allowing alternative descriptions of causal chains and, on the other hand, by taking into consideration social and political aspects besides the relationship between economics and environmental spheres.

Keywords: Catalonia, DPSIR, genetic "contamination", GMO coexistence, maize, stakeholders.

1. Introduction

Introduction and commercialisation of GMOs have generated huge controversy in Europe. On the one hand, proponents claim far-reaching societal benefits of GMOs and see in this technology the key for improving competitiveness and promoting economic growth (European Commission, 2002) or yielding agri-environmental benefits, specially for farmers (see e.g. Carpenter et al., 2002). On the other hand, opponents challenge the potential benefits and rise questions on the purposes and uncertainties related to the environmental and social impacts of this technology, as well as their social distribution (Altieri, 2005; Carr and Levidow, 2000; Schubert, 2002).

Despite this controversy in Europe, GM maize has been widely cultivated in Spain since 1998. Bt maize is the only GM crop with a commercial licence in the EU. It is grown in Spain (75.000 ha), particularly in Aragon and Catalonia, and in very small amounts in other European countries. In the Catalan province of Lleida GM maize represents more than 60% of the total maize surface. At the same time, the organic agriculture sector is also growing in importance (CCPAE, 2005), except for maize (Binimelis, 2008).

Introduction of agricultural GMOs has not been accompanied by public deliberation in Spain. Just recently, the discussion on the coexistence between GM crops and organic and conventional agriculture has raised issues on the current and future state of the agricultural sector in Catalonia and on the technical measures to be applied for avoiding unwanted presence of GM material in the conventional and organic production. This debate has been characterised by difficulties between the different stakeholders (public administration, conventional and organic farmers, farmers growing GM crops, environmental groups, business representatives) to establish a dialogue on how issues can be framed and what the concerns to take into account are (Binimelis, 2008). The lack of transparency and understanding of each others' positions contributes to the conflict.

The DPSIR model has been used by the European Environment Agency (EEA) and EUROSTAT as a communication tool to structure information about the interactions between society and the environment. In particular, it has been widely applied for organising systems of indicators and statistics, in relation to a policy aim. It is grounded in the assumption of the existence of causal relationships between the different components of the system: the Driving Forces, i.e. the underlying social and economic developments, induce Pressures on the environment and, as a consequence, the State changes. These changes in the condition of the environment can have Impacts on humans or the environment, which may cause societal Responses. For its simplicity, it is widely emphasized as an interdisciplinary communication tool between researchers and also between researchers and policy makers and stakeholders (see e.g. Gabrielsen and Bosch, 2003).

This potential, however, has recently been questioned (e.g. Maxim (this issue); Svarstad et al (2007)), arguing that the DPSIR framework has deficits as a tool for good communication due to its incapability to deal with multiple perspectives and definitions. For instance, in Svarstad et al. (2007), attention is drawn to the "strong realist view on knowledge behind the DPSIR", implying that the understandings of the environmental issues are narrowly presented as scientific truths, omitting different understandings of controversial issues. Finally, it is argued for the need to critically apply the DPSIR framework in specific cases, establishing a methodology that helps to incorporate perspectives and definitions of the problem stated by different stakeholders.

The aim of this paper is to critically apply the DPSIR model to the assessment of the agri-environmental situation in Catalonia, with special emphasis on the role played by GMOs. This is done through the implementation of the DPSIR definition developed within the ALARM project (see Maxim et al. (this issue)[1]). The application of the DPSIR model in this case, on the one hand helps in organising the information and, on the other, makes visible the differences in positions among stakeholders. It allows discussing the application of DPSIR schemes under conditions of uncertainty, in which a variety of narratives are present.

GM and organic agriculture as indicators – A literature review

A literature review discloses different approaches when considering GMO-based agricultural systems and organic agriculture within the DPSIR scheme. They differ both in the definition of the DPSIR categories themselves and the interpretation its significance in relation to the objective of the study. For a complete review of the use of indicators for assessing the role played by GMOs in the environment and agriculture, see Brauner et al. (2002).

The European Environment Agency (EEA) was initially including, in its reporting on the state of environment, the area planted with GMOs as an indicator (AGRI12). Although it was not formally classified in the DPSIR system, this indicator was related to structural, technological and management changes in the agricultural sector, which are associated to driving forces (Petersen, 2003). Use of GMOs has been also included as a driving force indicator by other authors. Hansen et al. (2002) classify it as a driving force indicator in their analysis and assessment of food safety using the DPSIR scheme. Notice that Hansen et al. (2002) target food safety while the purpose of EEA indicator scheme is to assess the state of the European environment. The demarcation of the object of study implies, in this case, the limitation of driving forces to three types of processes: the use of determinate compounds such as GMOs or the application of N; the use of technology and the structural developments of agricultural production, processing and marketing.

Other reports conceive the introduction of GMOs as a pressure. For instance, the OECD included “the introduction of new genetic material and species” as an environmental pressure indicator related to the theme “biodiversity and landscape” in its first "Core Set of Indicators for Environmental Performance Reviews" (OECD (1993) quoted in Brauner et al. (2002)). Other cases are the national environmental indicators in Italy, South Africa or Australia. This is

[1] For other examples of the implementation of these definitions to specific case studies, see Rodriguez-Labajos et al; Kuldna et al; and Omann et al. (in this issue). (This article will be published as part of a special issue).

consistent with the strict biosafety schemes (which include GMOs and invasive species) implemented by these countries. For instance, in Italy the issue is introduced through counting the area devoted to experimenting with GMOs in agriculture, considered as a pressure indicator (Mammoliti Mochet et al., 2003). In the case of South Africa, the indicator –distribution and abundance of GMOs invading natural systems- relates GMOs to their invasive potential. However, it is included as a dormant indicator, as it is considered that there is lack of data or knowledge in order to calculate it accurately (Le Maitre et al., 2002). Pressures are defined in the report as processes exerted on resources and ecosystems as a result of human activities (i.e. driving forces), including consumption and waste generation patterns and trends. For Australia, different types of indicators are proposed in relation with GMOs. Distribution and abundance of GMOs is included as a pressure indicator while control of exotic, alien and GMOs is also incorporated as response indicator (Saunders et al., 1998). Pressure is defined in this work as the human activities that affect the environment (note that the category "driving forces" was not included in the Australian report) while responses are characterized as the number of objectives settled and actions taken by humans to address perceived environmental problems or potential problems. Similarly, the United Nations Commission on Sustainable Development, on its turn, elaborated a series of indicators for sustainable development in line with the Agenda 21 process. The environmental sound management of biotechnology included both R&D expenditure on biotechnology and the existence of national biosafety regulations as response indicators under the D-S-R scheme.

Organic agriculture is also a relevant subject in this discussion. The area used for organic farming is included in the core set of indicators of the EEA. This is classified as a response indicator following the DPSIR model (EEA, 2005a). In the working definition of organic agriculture the contraposition of the use of GMOs to the organic production system "which puts a strong emphasis on environmental protection and animal welfare by reducing or eliminating the use of GMOs and synthetic chemical inputs" is explicitly mentioned (EEA, 2005b). Meanwhile, in the analysis done by Zalidis et al. (2004) to assess EU agri-environmental measures effectiveness, area planted with organic agriculture is included as an indicator of the main driving force, which in this case is agriculture.

This article is organised as follows. The next section characterises the Catalan maize sector and the current state of GMOs crops and organic farming. Then, the methodology of this case study is explained. The fourth section presents and discusses main results of the paper by organising the information on the agro-environmental stakeholders' assessment following the DPSIR scheme. The final section summarizes the findings and examines their implications on the present case study for policy-making.

2. The Catalan maize sector

This paper analyses the agri-environmental state of Catalan agriculture focusing on the role exerted by GMOs. This case study takes place in one of the European areas with more percentage of GMOs sown at a commercial scale. Its relevance is rooted in the fact that this situation has generated, on the one hand, an opportunity to reflect on what agricultural system is desired and what are the implications for biodiversity while, on the other hand, this deliberation has also allowed rethinking the scientific model and its relation to policy-making (science-policy interfaces). The notion of the GMOs themselves as threats (e.g. by conceiving them as biological invasions (Ewel et al., 1999; McNeely, 2001; Williamson, 1999)) or as positive responses to biodiversity loss will be here placed in the core of the discussion.

In Spain the introduction of GM maize took place in 1998, when five varieties with the modification Bt-176 and eleven of Mon810 were placed in the Register for Commercial Varieties. Both modifications were developed for insect resistance (especially targeting the European and Mediterranean corn borers: *Ostrinia nubilalis* and *Sesamia nonagrioides*). Since then, the number of available varieties has increased up to 61 in 2007. Farmers' acceptance of GM maize has been mixed in Spain. The GM surface represents about 10% of the total area sown with maize in 2004 (Ministry of Agriculture, 2004a). The highest concentration of GM maize is in the North-East of Spain (Aragon and Catalonia).

Maize production is an important agricultural activity in Catalonia, mostly related to the meat industry. It is especially concentrated in the province of Lleida, a leading European region involved in livestock raising. With more than 2.5 million pigs, it heads Spanish production on feed and fodder with 27,000 hectares cultivated with maize –of which around 15,000 were GM maize in 2006 (DARP, 2006). The area concentrates most of the agrarian activity in Catalonia, representing 12.1% of the employed population, while this percentage is only 2.3% for the whole region. However, the number of agrarian farms is diminishing, favouring land concentration (IDESCAT, 2003). Moreover, Spain imports maize from the largest GM maize producers, Argentina, Brasil and USA (Ministry of Agriculture, 2004b). These imports are presumed to have a high content of GMOs (European Commission, 2005). The biotech sector is also growing in importance in Catalonia. About one hundred biotechnological companies are located in Catalonia. Moreover, the project to develop a "Catalan Bioregion" intends to favour the creation of 60 biotechnology companies, with over 1,500 direct employments by year 2010 (ASEBIO, 2005). It should be noted that most of them are engaged in biomedicine. Still, it must be acknowledged that their presence could perhaps contribute to create an economic and political climate in favour of biotechnology in general.

Regarding the area sown with organic maize in Spain, there are limited data available. The Spanish Ministry of Agriculture has only published the figure for the total amount of cereals and legumes: 100,860 ha in 2003 (Ministry of Agriculture, 2004c). However, Brookes and Barfoot (2002) estimated the area of organic maize in Spain to be about 1,000 has. Finally, the use of non-hybrid maize varieties supposes around 16% of the total maize seeds in Spain (no data for Catalonia) (Ministry of Agriculture, 2004b).

3. Methodology of the case study

Research included a review of the official information available (including European Commission's press releases and communications, legislative documents and technical reports) as well as documents produced by other stakeholders. The second part of the study is based on field research in the province of Lleida, which started in 2002. Its aim is to consider stakeholders' viewpoints at the local level. To collect this information, qualitative techniques including workshops, group and individual in-depth interviews, as well as participant observation are used. Up to the end of 2006, 21 farmers, 6 managers of agricultural cooperatives and 3 agricultural engineers working in the local government's extension service were interviewed in the field.

In a third phase, other stakeholders, relevant at the policy level in relation to GMOs, agriculture and biodiversity conservation in Catalonia were targeted. It consisted of 18 semi-structured interviews and a quantitative questionnaire. The questionnaire included 35 statements that the respondents had to rank from 1 (totally disagree) to 4 (totally agree) designed to reinforce that stakeholders position themselves on issues related to the conception of GMOs, the potential risks and benefits associated with them and the coexistence between GM and non-GM, with emphasis in the biodiversity aspects[2]. Semi-structured interviews were divided in three thematic sections. The first one dealt with stakeholders' perception on the state of agricultural environment, while the second was on the information and communication linked to the GMOs issue in Catalonia. The third one included questions on the coexistence normative proposal.

The results of this paper show mainly the findings on the first section of the questionnaire, in which questions targeting the different elements (driving forces, pressures, state, impacts and responses) of DPSIR model were included. Discourse analysis was performed to elicit

[2] Some statements were based on a previous research conducted by Kvakkestad et al. (2007); others were specific for this case study.

stakeholders’ narratives. Discourse analysis is understood here as a way to understand a shared system of knowledge or belief and the social practices in which it is produced, “through which meaning is given to physical and social realities” (Hajer, 1995, p. 44).

Stakeholders for the third part were selected among politicians and public administrators, representatives from agricultural unions, experts from the genetic engineering and organic agriculture fields, as well as environmental and consumers’ organisations. All of them were interviewed as representatives of their institutions. During the interview, participants were asked to list relevant stakeholders that should participate in the debate according to their point of view. In doing so, internal consistency in the selection of stakeholders was checked so as to ensure representation of the relevant perspectives. The different participants were asked, at the end of the interview, to position the institution they represent on the use of GMOs in agriculture.

Qualitative research usually takes into account that expressions of the interviewees should be interpreted according to the context, because it is possible that one interviewee wants to make public a speech or attitude in a context, but change them when it is in another context. While this is true, in the present article the interviews have been used to classify discourses on the main trends on the state of the agro-environment and also to build up a rich typology of driving forces, and it does not matter whether one particular interviewee would change his/her statements in a different context. Thus, a civil servant might admit in private that norms regulating distances between GM and non-GM fields are impossible to apply while in public he would be reluctant to do so. What matters is that both opinions are found in society.

4. The DPSIR framework applied to the agroenvironmental state of the Catalan agriculture – special emphasis on GMOs.

In this section, stakeholders and their positions are characterised. Second, information from the case study is organised according to the DPSIR model.

Stakeholders

The list of the 18 participant stakeholders is in Table 1. They are characterised and grouped following their own description of their work and their relation to the agro-environmental state of Catalonia, with a special focus on GMOs and biodiversity. A third column shows the position that stakeholders declare themselves to have towards the use of GMOs in agriculture.

Table 1: Participant stakeholders

Stakeholder[3]	Description	Position
Agrarian Cooperatives Federation	Two agricultural engineers working as technicians. The Federation groups more than 60% of the agrarian cooperatives in Catalonia, representing around 85% of the Catalan production	It is an available technology. Risks should be assessed as in any technology
Agribusiness company representative	Genetic and agricultural engineer, spokesperson of a major company selling GM seeds in Spain	Positive for GMOs
Agricultural engineer (1)	Organic agriculture engineer developing and conserving local varieties	Against GMOs
Agricultural engineer (2)	University professor and researcher, specialist in extensive crops	No position
Catalan agriculture department technicians	Two agricultural engineers working as technicians in the rural innovation unit, in charge of technology transfer	Observer
Consumers' organisation technician	Environmental scientist, technician of the environmental department of a consumers' organisation	Against GMOs due to precautionary principle
Development NGOs technician	Technician working in the Catalan Development NGOs Federation, campaigner of the food sovereignty programme.	Against GMOs
Environmental organisation spokesperson	Biologist, representative of an international environmental NGO in Catalonia	Negative for GMOs, very critical
Farmers union representative (1)	Maize farmer, member of the executive board of the union (representing 75% of Catalan farmers). Spokesperson on food security and quality	Against GMOs
Farmers union technician (2)	Technician agricultural engineer, working for the second most representative union in Catalonia	There is not enough experience and information concerning this technology
Green Party representative	Biologist, member of the Catalan Parliament representing the left-wing green party, which is in the Catalan government	GMOs refusal
International NGO member	Agronomist, working in an international NGO promoting sustainable management and use of agricultural biodiversity based on people's control and local knowledge	Against GMOs
Molecular biologist	Biologist and genetist researching in an institution depending on the Spanish	Neutral

[3] In light of the conflict that surrounds GMOs, the use of proper and institution names is avoided to ensure privacy of participant stakeholders.

	government	
Organic agriculture certification body representative	Director and technician of the organic agriculture certification body. It is a public body depending on the Catalan government	For the no existence of GMOs due to the difficulties in coexisting with organic agriculture in Catalonia
Public research institution on agricultural technology	Biotechnologist working in the development of new GM varieties and research related to pollen flow (coexistence) in a research institution depending on the Catalan government	We should not disregard the advantages that can be provided by this technology

From the analysis of stakeholders' opinions regarding the use of GMOs in agriculture, several positions can be identified. Positive reactions can be observed in stakeholders directly involved in GMOs development and commercialisation while negative responses are linked with those stakeholders involved in social movements (NGOs, consumer associations), one of the farmers union and organic agriculture. Researchers related to biotechnology research position themselves as neutral. Finally, others decided not to position themselves clearly, appealing to the strong conflicts on this issue.

In spite of the different positions on agricultural GMOs as a broad scientific and social issue, when analysing their perceptions of the role that GMOs play in the Catalan agriculture, only two groups are evidenced. The first group includes stakeholders related to organic agriculture, the farmers unions, the consumers' organisation, environmental and development NGOs and the Green Party representative. The second is integrated by the genetic engineers, the spokesperson of an agribusiness company and the Catalan agriculture department.

Catalonia's agriculture crisis under the light of DPSIR

In this section, data collected from in-depth interviews and questionnaires is organised following the DPSIR model. The assessment of the state of agriculture in Catalonia –and the role played by GMOs- is done for the present time, although stakeholders were also asked to make projections for short and medium time.

A state of crisis

The starting point of this research was the description made by stakeholders on the state of the agroenvironment in Catalonia, focusing on the role played by GMOs. The state is defined here, following Maxim et al. (this issue), as the quantity of biological (such as biodiversity erosion), physical (i.e. landscape fragmentation, decreasing number of farms) and chemical phenomena (i.e. pollution) chosen by stakeholders to describe the risks of not desirable agri-environmental changes in Catalonia.

The generalised characterisation of the Catalan agriculture was as in a state of crisis. All interviewed stakeholders coincided in this statement, with only small differences depending on the agricultural sector but concurring in the general assessment. The results among policy level relevant stakeholders fully coincide with previous research among farmers.

All stakeholders agreed in labelling conventional agriculture as highly polluting due to the high use of synthetic inputs or the agricultural oil dependency. The characterisation of agriculture as a source of pollution is strongly linked with slurry from pigs, which is considered a main agro-environmental issue in Catalonia. Following this narrative, conventional agriculture is unanimously described as being currently unsustainable. Other sides of this description are the overall characterisation of the farmers' situation, described as "desperate", "discouraged", "without an easy solution" due to low economic profitability. These circumstances lead to a diminishing number of farms and agricultural land in actual use, which is also considered as a threat for agricultural biodiversity and landscape conservation. It is interesting that nobody feels responsible for this situation, partly because most of the driving forces are considered by most stakeholders as external or even given.

Regarding maize production, all stakeholders coincide in recognising the growing importance of GM seeds. This situation, as it will be discussed, is assessed differently by the diverse stakeholders. Areas planted with GMOs have been continuously increasing since its introduction in 1998. In that sense, stakeholders have also referred to the dependency of Catalan agro-industry on imported animal feed and fodder which, in the case of maize and soy, are mostly GM. Another shared view regarding GMOs highlights power concentration in agribusiness companies, including access to patenting. The role of organic agriculture is characterised as still minor, but growing in importance. This general trend is not being followed by organic maize production, which has diminished since 1998. It is seen with concern by some stakeholders, especially those linked with organic sector (Binimelis, 2008).

In despite of the overall coincidences, the group of stakeholders which is prone to the use of GMOs includes in the description of the state the consequences of the lack of implementation of the potential for modernisation –and specially biotechnology- which is seen as a promising technology for mitigating the environmental impacts of high input agricultural systems. A second difference in the description of the state is the inclusion by GMOs opponents of genetic contamination in the characterisation of pollution. This concept is used for referring to the unwanted process that transgenes from GM crops move to other organisms and become established in natural or agricultural ecosystems (McAfee, 2003; Walters, 2004; Verhoog, 2007; Binimelis, 2004). It opens the possibility to cause direct effects to biodiversity by affecting non-target species or relatives through unintentionally transferring them traits of the GMOs. This contested statement and its implications will be discussed below.

<u>Driving forces</u>

Driving forces are changes in the social, economic and institutional systems, which are triggering directly and indirectly pressures on the environmental state of agriculture (Maxim et al., this issue). Focus is placed in the discussion on the role played by GMOs. Four non-hierarchical but interacting levels of driving forces can be distinguished (Rodríguez-Labajos et al., this issue), influencing the structure and relation between the social, economic, political and environmental systems. Socio-economic activities directly linked with the pressures are “primary driving forces”. They correspond to the level of management. Primary driving forces are considered to be more flexible in the short term than the “secondary driving forces”, the policy level. In the long term and with a broader spatial sphere of influence there is the level of “tertiary driving forces”, ideology and lifestyle. Finally, the “base driving forces” include fundamental trends, such as demographic or cultural, that are only influenced by social decisions in the long term. A characterisation of the main driving forces influencing the current agro-environmental state and linked with GMOs introduction is presented in table 2, after stakeholders’ perceptions.

Table 2: Driving forces of the present agro-environmental state in Catalonia

Level	Description / Indicators
Basic driving forces	Demographic factors
	Socio-political factors
	Economic factors
	Scientific and technological factors
	Cultural factors
Tertiary driving forces: Ideology and lifestyle	**Global trends**
	Globalisation of economies and trade
	Globalisation of consumption patterns: increasing demand for imported products
	Consumption patterns
	Intensification of the demand for more environmental-friendly and traditional foods
	Changes in the cultural system
	De-linkage between rural and urban populations and lifestyles

Level	Description / Indicators
	Loss of agriculture's social importance
	Knowledge information and technological progress
	Change of the demand for new technological developments in agriculture
Secondary driving forces: Policy level	**Common Agricultural Policy**
	Subsidies linked to production
	International treaties, laws and regulations
	Free trade agreements
	Land use policy
	Changes in land use policies in favour of urbanisation and tourism
	Hydrological policy: shifts from dry to irrigated land
	Environmental policy
	Regulations on food security and quality
	Changes in chemical policy
	Research policy
	Promotion of research in biotechnology
Primary driving forces: Management level	**Changes in agricultural practices**
	Increasing importance of input and technological-intensive agriculture
	Abandonment of arable land
	Land use practices
	Increasing land concentration
	Intensification of urbanisation
	Changes in landscape planning
	Trade
	Increasing number of import products
	Tourism
	Increasing flow of tourists into rural areas
	Technological transfer practices
	Low level of public technological transfer in agriculture

Changes in the cultural system, linked to demographic and socio-economic factors, are considered important basic driving forces by the interviewed stakeholders. Internal migratory movements from the countryside to urban areas have lead to the depopulation of permanent inhabitants in rural areas. This trend is reverted only temporarily, associated with the holiday periods or when temporary workers arrive to the rural areas. Moreover, out migration of rural young population translates in the ageing of rural population. The process has led to a "de-linkage" between most of the population and the rural areas and therefore, the agricultural practices. Following it, most stakeholders argue that agriculture has lost social importance and has been relegated to a secondary sphere in public policies.

Regarding tertiary driving forces, there was agreement pointing out to globalisation of economies and trade as major driving forces. Consumption patterns are internationalised as the demand for imported products is increasing (e.g. maize and soybeans as commodities). Changes in consumption patterns are also mentioned at a local scale, as there is an increasing demand for the so-called "environmentally-friendly", "traditional" and "healthier" food. Also changes in knowledge, information and technological progress are referred to. The production-oriented model of agriculture and the changes in the social and cultural system have driven agriculture to specialisation (e.g. integration model in animal farms) and technification. This process, which started in Spain during the 1960s[4], occurs along the food chain: from hybrid seed varieties and imported animal races to processing at the final stages. GMOs proponents include also among the tertiary driving forces the so-called "risk adversity" behaviour of agrobiotechnology opponents.

Secondary driving forces are linked to policy developments. Common Agricultural Policy (CAP) is pointed out as the major driving force, linked to subsidies geared to increase production. Besides CAP subsidies, increase of area sown with maize is related to hydrological policy and the conversion of dry to irrigated land, resulting in land concentration. Finally, maize internal production is also related to international treaties, laws and regulations, especially connected with maize quota agreements. Other cited land use policies are the changes in favour of urbanisation, related to second residences and tourist activities, competing with agricultural uses.

In regard to environmental policies, interviewed stakeholders not linked with the organic sector refer to the environmental and safety regulations as an obstacle for competing in the global market. For instance, obligations within the REACH policy (European registration, evaluation and authorization of chemicals system) to substitute actual commonly used broad spectrum herbicides linked to maize production were mentioned. Driving forces related to the research policy have also been pointed out. Most stakeholders identify Catalan research policy related to agronomy as oriented towards the implementation of biotechnology in agriculture, although some disagreements exist regarding this issue.

Primary driving forces are those at the management level. Management is defined here as policy enforcement but also to refer to those processes derived from shared practices. They are mostly

[4] In the period of 1960s and 1970s the farming modernisation in Spain starts. The agrarian surface in Spain was reoriented to feed and fodder crops, such as maize. Moreover, during the 60s the importation policy began – through a Decree authorising importations- for this type of commodities (Domínguez-Martín, 2001).

linked with the implementation of agricultural policies. Stakeholders refer to intensification of agriculture linked to the production-oriented policy. The process of modernisation comes along with the promotion of technology and an input intensive agricultural model. Changes in land use practices are also important. Abandonment of arable land due to demographic and socio-economic grounds is stated. This abandonment, together with new land irrigation policies, has driven to a decreasing number of farms. In fact, only those farms with more than 100 ha have grown in Catalonia (IDESCAT, 2003). This is also connected with urbanisation patterns and changes in landscape planning, as the promotion of rural areas as tourism destinations. Finally, lack of public technological extension is also brought up by some of the interviewed persons.

Pressures on the state of the agro-environment

Adjusting the definitions used in Maxim et al. (this issue) to this case study, pressures are defined here as the consequences of the implementation of an agricultural model which are perceived by stakeholders as having the potential to produce changes in the state of the agro-environment leading or contributing to impacts. Although stakeholders share their views concerning the description of most of the driving forces, differences can be found regarding their perceptions on what are the pressures related to GMOs on the agro-environmental state.

The first group argues that GMOs represent a negative pressure for the agro-environmental state, as they worsen the environmental and social impacts of the present production model. This technology is discussed as representing a uniquely rapid increase in intensification (e.g. Watkinson et al., 2000). Moreover, it is argued that this process damages integrity of organic and conventional agriculture and the seed system. This point is connected with the reflection on uncertainty and irreversibility of the process. In that sense, GMOs are ranked, in the quantitative questionnaire as contributing to a decrease of agrobiodiversity. Factors influencing this, according to stakeholders, encompass administration support to biotechnology research and introduction of GMOs, lack of social debate, pressures by agribusiness companies and deficiencies in communication mechanisms.

The second group assesses the introduction of GM maize, as it will be discussed below, as a positive response to the crisis, while characterising GMOs refusal as being a negative pressure. These stakeholders argue that there exists a technical compatibility between GM crops and organic and conventional farming as not substantial differences can be found between them. Concerning the potential of GM crops to pose risks to biodiversity, no consensus is found within the group. However, a general statement is that the introduction of new GM varieties results, to a greater or lesser extent, in an increment of the agricultural biodiversity, enhancing also the contribution of biotechnology for sustainability. From that point of view, the concept of contamination should be neglected as it implies a pejorative quality of GMOs.

Impacts

Impacts are changes in the environmental functions, affecting the social, economic and environmental dimensions, and which are caused by changes in the state of the agrobiodiversity, as examined by Maxim et al. (this issue). As we have already discussed, pressure characterisation varies among stakeholders. These differences in perceptions are subsequently linked to the definitions on impacts. Therefore, the two groups distinguished above maintain their differences when discussing the impacts.

The first group of stakeholders agrees in considering the so-called genetic contamination as a major impact on biodiversity exerted by the introduction of GM maize. Stakeholders within this group have argued that this could have implications from environmental, agronomics, economics and socials points of view, raising questions on food safety, integrity of organic agriculture and the seed system or concerning consumer’s rights. The concept of genetic contamination is linked to both conventional and organic farming. However, as price for conventional and GM maize is not differentiated, and labelling regulations[5] leave a threshold for adventitious presence of GM traces, only few cases concerning conventional agriculture have been reported by farmers. On the contrary, most organic farmers and consumers reject the presence of GM material in organic products, which was prohibited in organic products by the European organic agriculture and farming legislation (Regulation 2092/91/EEC)[6] and discarded by the International Federation of Organic Agriculture Movements (IFOAM) and the Codex Alimentarius[7].

The second group of stakeholders starts from the basis that GM varieties presently sown in the area have been approved and thus, risk assessment has been conducted, among others, by the European Food Safety Agency. From this point of view, GM varieties are considered as safe as conventional ones or even safer as they have gone through more exhaustive risk assessments. Another important agreement within this group is to conceive genetic engineering as a

[5] Labelling thresholds were established in 0.9% for authorised modifications of each ingredient contained by the product (Regulation (EC) No 1830/2003).

[6] A new regulation, (CE) 834/2007 has been recently approved, which has to be implemented after the 1st of January 2009. It is explicitly allowing a 0,9% presence of GMOs in organic production.

[7] The Codex Alimentarius was created in 1963 by the Food and Agriculture Organisation and the World Health Organisation. It is a mechanism under international law on agreements which allows the parties -practically all of the countries involved in international trade of agricultural products- to document their mutual understanding of requirements for foodstuffs.

continuation of conventional plant breeding, which can increase control and predictability of the expressed traits. Therefore, the concept of contamination is rejected and the cases in which unwanted presence of GM material have been found become only a matter of economic dispute, since organic production suffers diminishing economic profit. Finally, stakeholders classified in the second group bring up the opportunity costs of not using agro-biotechnology as an impact derived from the rejection of GMOs. In that sense, it is difficult to compete in the global market with basic products such as conventional maize.

Responses

Responses are defined as policy actions which are directly or indirectly triggered by the perception of impacts and which attempts to prevent, eliminate, compensate or reduce their consequences. All stakeholders have concurred in targeting the so-called “quality agriculture”. In that sense, the highly fragmented Catalan agricultural landscape is seen at present as a factor for the loss of competitiveness in the global market but it is also considered to have a future potential. This fragmented landscape, together with a highly variable topography and climatic conditions, are the basis for differentiated quality agriculture. However, the definition of quality is a matter of disagreement. On the one hand, the first group argues that quality would represent an organic agriculture-based model –which would exclude GMOs-, with a much higher share in the use of local seed varieties and direct selling mechanisms. On the other hand, the second group agrees in assessing the introduction of GM maize as a positive response towards achieving quality, obtaining a more competitive and environmentally-friendly agriculture, e.g. using less pesticides. In that sense, it is argued that an abolishment of restrictive legislation for GMOs commercialisation, which burdens the producers, would contribute to enhance also competitiveness in global markets.

5. Discussion

As it has been developed, the role played by GMOs in the agro-environmental state of Catalonia can be described using alternative narratives or frames. Our results show that, on the one hand, different descriptions of the problem are possible, as different frames of the policy-objective exist. These empirical results coincide with previous studies on contending European agri-environment discourses, which categorized them as “eco-efficient” in the case of GMOs proponents and “apocalyptic” for the case of opponents. A third discourse, “managerialist” has not been clearly identified in the case study (Levidow and Carr, 2007). It is important here to note that discourses are a shared way to reflect on a phenomena and their description always entails a reduction of the multiple views which are representing. In fact, the debate on GMOs has been characterised by confrontation at the societal level, but also by low consensus on the scientific issues and the analytical methods to be applied (Busch et al., 2004). The existence of different narratives depends on complex and value-laden considerations, shaped by interests embedded in different cultural, ethical and socio-economic context. Educational background seems to have also an influence in these contested perceptions among experts (Kvakkestad et al., 2006).

In spite of this, current definitions of the DPSIR framework (i.e. the ones used by the EEA (2003)) establish the need for a scientific causal proof of the relationship between pressures and the impacts perceived in the socio-economic system, relying on a strong realistic view of knowledge. The establishment of the causal link between the different DPSIR categories is not only depending on the world-view, as it has been discussed, but it is also a function of the state of knowledge, the consideration on uncertainty for policy-making, the agreement on the demarcation of the specific system of interest which is under analysis and the scale to be considered (Maxim et al., this issue). In that sense, the framing and objective of the analysis, the assessment of the significance of the impacts, the selection of indicators or aspects such as the weighting factors cannot only be decided from a scientific perspective, but are politically-motivated “as each indicator system is generally based either explicitly or implicitly on a defined objective specifying the direction in which reality is to change” (Brauner et al., 2002).

6. Conclusion

In this article the DPSIR model was used to organise information on the state of agro-environment in Catalonia, focusing on stakeholders’ perceptions on the role that GMOs play in the agro-environmental system. Results show that the application of this framework allows displaying the available information, as well as to make explicit the different stakeholders’ positions.

EEA DPSIR definition is based in causal relationships between the different components of the system in a mechanistic way. This could result in a communication deficit (Svarstad et al, 2007) when applied to complex situations, which are characterised by non-linearity, in which not all the relevant information is available or indeterminacy in framing the issue exists. Definitions proposed by ALARM (see Maxim et al, this issue) try to overcome some of these shortcomings, allowing to incorporate contested discourses. Differences in conceptualising the same issue –the introduction of GMOs in agriculture- can lead to diverse policy actions. Broadening the scope of DPSIR definitions combining the 4 spheres of the sustainability frame could allow for the incorporation of multiple causalities and more complete descriptions of the system as well as to incorporate socio-political aspects to the analysis (Maxim et al., this issue). In this way, different discourses can be produced on the basis of an examination of the stakeholders’ narratives, contributing to a more transparent and inclusive use of the DPSIR framework. However, transparency does not lead necessarily to conflict resolution.

Thus, defining the introduction of GMOs as a pressure or as a response could bring together an entirely different agricultural model orientation, originating also differences regarding regulatory actions, research expenditure, changes in management strategies or actions by public opinions. Making this information more transparent could help to improve the debate but also to sharpen it, by bringing into the open the underlying coincidences and differences. Also, recognising and making explicit complexity and uncertainty would help to improve the decision-making process by incorporating all legitimate perspectives into the analysis.

Acknowledgements

Comments by Joan Martínez Alier, Nicolas Kosoy, Ines Oman, Kaja Peterson and Mariana Walter are gratefully acknowledged. This research has been partly financed by the EC within the FP6 Integrated Project “ALARM” (COCE-CT-2003-506675).

References

Altieri, M., 2005. The myth of coexistence: why transgenic crops are not compatible with agroecologically based systems of production? Bulletin of Science, Technology and Society, 25(4):361-371.

ASEBIO (Asociación de Empresas dedicadas a la Biotecnología), 2005. Informe 2004. Madrid, 181 pp. Available at: http://www.asebio.com/publicaciones.

Binimelis, R., 2004. Co-existence of organic and GM agriculture in Catalonia. Master dissertation. Environmental Sciences PhD program, Autonomous University of Barcelona.

Binimelis, R., 2008. Coexistence of plants and coexistence of farmers: Is an individual choice possible? Journal of Agricultural and Environmental Ethics. DOI 10.1007/s10806-008-9099-4.

Brauner, R., Tappeser, B., Hilbeck, A., and Meier, M.S., 2002. Development of Environmental Indicators for Monitoring of Genetically Modified Plants Environmental research of the federal Ministry of the Environment, Nature Conservation and Nuclear -safety. Research Report 299 89 405, UBA-FB 000219/e. Texte 28/02. Berlin, 232 pp.

Brookes, G. and Barfoot, P., 2003. Co-existence of GM and non GM crops: case study of maize grown in Spain. PG Economics Report. Available at: http://www.pgeconomics.co.uk/crop_coexistence_spain.htm

Busch, L., Grove-White, R., Jasanoff, S., Winickoff, D. and Wynne, B., 2004. Amicus Curiae Brief submitted to the dispute settlement panel of the WTO in the case of EC: Measures affecting the approval and marketing of biotech products.

Carpenter, J., Felsot, A., Goode, T., Hammig, M., Onstad, D. and Sankula, S., 2002. Comparative environmental impacts of biotechnology-derived and traditional soybean, corn and cotton crops. Council for Agricultural Science and Technology, Ames, Iowa.

Carr, S., and Levidow, L., 2000. Exploring the links between science, risk, uncertainty, and ethics in regulatory controversies about genetically modified crops. Journal of Agricultural and Environmental Ethics, 12:29-39.

CCPAE, 2005. Estadístiques 2005. Available at: http://ccpae.org/estadistiques.html

DARP, 2006. Varietats de panís. Technical Report, 10. Catalan Agriculture and Fisheries Department, Barcelona.

Domínguez-Martín, R., 2001. Las transformaciones del sector ganadero en España (1940-1985). Ager, Revista de Estudios sobre Despoblación y Desarrollo Rural, 1:47-83.

European Commission, 2002. Life sciences and biotechnology — A strategy for Europe. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. COM(2002)27 final. Luxembourg, 23rd January. Available at: http://europa.eu.int/comm/biotechnology/pdf/com2002-27_en.pdf

European Commission, 2005. Final report of a mission carried out in Spain 07/03/2005 to 11/03/2005 concerning controls on food & feed containing, consisting or produced from GMO. DG(SANCO)/7632/2005-MRFinal Directorate F – Food & Veterinary Office, Health & Consumer Protection Directorate General, European Commission.

European Environment Agency, 2005a. The European environment. State & Outlook, 2005. Copenhagen.

European Environment Agency, 2005b. Agriculture and Environment in EU-15 –the IRENA indicator report. Office for Official Publications of the European Communities, Luxembourg. Report 6/2005.

Ewel, J.J., O'Dowd, D.J. Bergelson, J., Daehler, C.C., D'Antonio, C.M., Gómez, L.D., Gordon, D.R., Hobbs, R., J., Holt, A., Hopper, K.R., Hughes, C.E., LaHart, M., Leakey, R.R.B., Lee, W.G., Loope, L.L., Lorence, D.H., Louda, S.M., Lugo, A.E., McEvoy, P.B., Richardson, D.M. and Vitousek, P.M., 1999. Deliberate Introductions of Species: Research Needs. BioScience, 49(8):619-630.

Gabrielsen, P. and Bosch, P., 2003. Environmental indicators: typology and use in reporting. European Environmental Agency internal working paper.

Hajer, M.A., 1995. The politics of environmental discourse. Ecological modernization and the policy process. Oxford University Press, 344 pp.

Hansen, B., Alrøe, H.F., Kristensen, E.S., Wier, M., 2002. Assessment of food safety in organic farming. Working Paper no. 52, Danish Research Centre for Organic Farming (DARCOF), Tjele.

IDESCAT, 2003. Estadística de l'estructura de les explotacions agràries, 2003. Estadística econòmica / sectors econòmics. Statistical Department of Catalonia.

Kuldna, P., Poltimäe, H., Luig, J., Peterson, K. (this issue). Human pressures on pollinators: an application of the DPSIR model.

Kvakkestad, V., Gillund, F. and Kjolberg, K.A., 2007. Scientists' perspectives on the deliberate release of GM crops. Environmental Values, 16(1):79-104.

Le Maitre, D., Reyers, B., King, N., 2002. National Core Set of Environmental Indicators. Specialist Report 3, Vol. 3. Environmental Information and Reporting National Department of Environmental Affairs and Tourism, South Africa, 97 pp.

Levidow, L., and Carr, S., 2007. GM crops on trial: Technological development
as a real-world experiment. Futures, 39:408–431.

Mammoliti Mochet, A., Morra di Cella, U., Trèves, C., 2003. Indicatori per il reporting sulla biosfera. Agenzia per la protezione dell'ambiente e per i servizi tecnici, Roma, 195 pp.

Maxim, L., Spangenberg, J., O'Connor. This issue. An analysis of threats to biodiversity under the DPSIR approach.

Maxim, L. This issue. Driving Forces of chemicals risks for the European biodiversity.

McAfee, K., 2003. Neoberalism on the molecular scale. Economic and genetic reductionism in biotechnology battles. Geoforum, 34: 203-219.

McNeely, J., 2001. Invasive species: a costly catastrophe for native biodiversity. Land Use and Water Resources Research, 1:1–10.

Ministry of Agriculture, 2004a. Sales of seeds for the years 1998, 1999, 2000, 2001, 2002 and 2003. Secretary of Agriculture and Alimentation. Spanish Office of Vegetal Varieties.

Ministry of Agriculture, 2004b. Anuario de estadística agroalimentaria. Madrid.

Ministry of Agriculture, 2004c. Producción nacional de semillas, histórico 2003. Madrid.

Omann, I., Stocker, A., Jäger, J. (this issue). Climate change as a threat to biodiversity: An application of the DPSIR approach.

Petersen, J.E., 2003. The EEA agri-environment indicator core set. Sub-group "Agriculture and Environment", of the Agricultural Statistics Commitee of the Working Group "Environment and Sustainable Development". Joint Eurostat/EFTA Group. Doc. AE/WG/051/08.1.

Rodríguez-Labajos, B., Monterroso, I. and Binimelis, R., (this issue). Multi-level driving forces of invasive species.

Saunders D., Margules C; Hill, B., 1998. Environmental indicators for national state of the environment reporting – Biodiversity, Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra, 68 pp.

Schubert, D., 2002. A different perspective on GM food. Nature Biotechnology, 20(10): 969.

Svarstad, H., Petersen, L.K., Rothman, D., Siepel, H., Wätzold, F., 2007. Discursive biases of the environmental research framework DPSIR. Land Use Policy, 25(1):116-125.

Verhoog, H., 2007. Organic agriculture versus genetic engineering. Wageningen Journal of Life Sciences, 54(4):387-400.

Walters, R., 2004. Criminology and genetically modified food. British Journal of Criminology, 44:151-167,

Williamson, M., 1993. Invaders, weeds and the risk from genetically manipulated organisms. Experimentia, 49:219-224.

Zalidis, G.C., Tsiafouli, M.A., Takavakoglou, V., Bilas, G., Misopolinos, N., 2004. Selecting agri-environmental indicators to facilitate monitoring and assessment of EU agri-environmental measures effectiveness. Journal of Environmental Management, 70(4):315-321.

Article 4:

’Transgenic Treadmill’: Responses to the emergence and spread of Glyphosate-Resistant Johnsongrass in Argentina

---

Accepted for publication in Geoforum

’Transgenic Treadmill’: Responses to the emergence and spread of Glyphosate-Resistant Johnsongrass in Argentina

Rosa Binimelis[1]*, Walter Pengue[2] and Iliana Monterroso[3]

(1) Institute of Environmental Science and Technology – Autonomous University of Barcelona
(2) Grupo de Ecología del Paisaje y Medio Ambiente, Universidad de Buenos Aires
(3) Área de Medio Ambiente, Recursos Naturales y Desarrollo Rural, FLACSO Guatemala

*Corresponing author: rosa.binimelis@uab.cat, rosa.binimelis@gmx.net

Abstract
The broad-spectrum herbicide glyphosate has become the largest-selling crop-protection product worldwide. The increased use of glyphosate is associated with the appearance of a growing number of tolerant or resistant weeds, with socio-environmental consequences besides loss of productivity. In 2002, a glyphosate-resistant biotype of johnsongrass (*Sorghum halepense* (L.)) appeared in Argentina, now covering at least 10.000 hectares. This paper analyzes the driving forces behind the emergence and spread of this weed. Management responses and their implications are also examined.

Preventing strategies against glyphosate-resistant johnsongrass fail because of the institutional setting. Reactive measures, however, imply transferring the risks to the society and the environment through the introduction of novel genetically modified crops, that allows the use of yet more herbicide. This in turn reinforces the emergence of herbicide-resistant weeds, constituting a new phenomenon of intensification, the “transgenic treadmill”.

Keywords: Argentina, economics of bioinvasions, genetically modified soybean, glyphosate-resistant weeds, herbicide treadmill, johnsongrass, transgenic treadmill.

1. Introduction

The use of the broad-spectrum herbicide glyphosate began in the 1970s. Since then it has grown steadily to become the largest-selling single crop-protection product worldwide. Over the last years, the agricultural use of glyphosate has risen due to price reductions, to an increase in supply associated with patent expiration, also to further implementation of minimum and non-tillage practices[1] and to the adoption of genetically modified (GM) glyphosate-resistant (GR) cultivars (Woodburn, 2000).

The appearance of tolerant or resistant weeds is related to an increased use of glyphosate, which, in turn, implies environmental and monetary costs beside productivity losses (Service, 2007). Although initially considered a low-risk herbicide for the development of herbicide-resistance by industrial scientists (Bradshaw et al., 1997), the first records of GR-weeds date from 1996 in Australia. Currently, 14 GR weeds have been documented worldwide (Heap, 2007; Valverde, 2007; Powles, 2008). This article deals with a highly invasive weed called johnsongrass. Several GR cases appeared in Argentina while two others were reported by the University of Arkansas, the Mississipi State University and Monsanto in the USA (Monsanto, 2008). In Argentina, additionally, some common weeds such as *Parietaria debilis, Petunia axilaris, Verbena litoralis, Verbena bonariensis, Hybanthus parviflorus, Iresine diffusa, Commelina erecta* and *Ipomoea sp*. have been reported to be glyphosate-tolerant (Papa, 2000).

The appearance of herbicide-resistant weeds associated with an increased consumption of glyphosate by GR cropping systems has become one of the main ecological risks when releasing GMOs to the environment (Altieri, 2005; Barton and Dracup, 2000; Ervin et al., 2003; Martinez-Ghersa et al., 2003; McAfee, 2003; Powles, 2003; Snow et al., 2005; Steinbrecher, 2001). Until today, those documented cases have been solely assessed from an agronomic perspective rather than accounting for a broader context (Beckie, 2006; Duke and Powles, 2008; Powles, 2008). In this paper we will review and discuss the emergence of GR johnsongrass (*Sorghum halepense* (L.)) biotypes in Argentina and its associated management strategies by means of analysing the political, economic and institutional driving forces leading this to phenomenon. We also devote part of the paper to analyse the consequences for rural dynamics.

In Argentina, over 16 million hectares are dedicated to GM GR soybeans production; glyphosate substitutes for tillage practices. Johnsongrass is a cosmopolitan perennial grass native to the Mediterranean region, and considered as one of the ten worst weeds in the world (FAO, 2007). It was introduced in Argentina in the beginning of the 20th century as forage but by 1936 it was already banned for agricultural purposes. However, due to its highly invasive nature, it continued spreading and became a key restrictive factor for the agricultural production model. The technological package associated with Roundup Ready

[1] Non-tillage practices belong to agronomic conservation systems in which the crop is sown over the stubble of the former crop. The soil is not turned over and worked with the minimum movement possible. The system facilitates erosion reduction and higher production under continuous agriculture.

soybeans was believed to control the pest by the mid 1990s. However, Monsanto's technicians just recently reported a GR johnsongrass biotype (Heap, 2007). Although the first plots with GR johnsongrass appeared in the north of Argentina by 2002, it can now be found practically in every agricultural region of the country.

Its appearance can be linked to some of the main risk factors associated to the evolution of herbicide-resistant weeds discussed in the weed-resistant management literature. Some of these risks arise from the frequent application of highly effective herbicides, such as glyphosate, in intensive low-diversity cropping systems, and the presence of annual weed species occurring at high population densities and characterised by its wide distribution, large genetic variability, prolific seed production and its efficient dissemination (Powles, 2003; Beckie, 2006).

The political economy of agrarian modernization and biotechnology, and the economics of bioinvasions can offer additional insights to understand the mechanisms of herbicide-resistant weeds' appearance and spread, as well as offering a novel perspective on its implications. Agricultural biotechnology has posed new and cumulative challenges to the future of rural spaces (Bridge et al., 2003; Gibbs et al., 2008; Marsden, 2008). In that sense, controversies on GMOs evidence a clash between agricultural paradigms and development alternatives (Altieri, 2005; Binimelis, 2008; Levidow and Boschert, 2008; Herrick, 2005; Lyons and Lawrence, 1999; Lyson, 2002; Marsden, 2008; McAfee, 2003; 2008; Verhoog, 2007). These, in turn, intensify previous differences born from the Green Revolution and its social and environmental consequences (Buttel and Barker, 1985; Buttel et al., 1985).

As we will argue, GM techniques became the cornerstone for the development of the agro-industrial model in Argentina. Biotechnology provided a basis for dealing with technical problems such as large-scale intensive-capital monoculture (e.g. weed management) (Marsden, 2008), fuelling the expansion, integration and internationalization of the soybean production and commercialisation in detriment to other alternatives (Pengue, 2005). In that sense, the diffusion of GM technology took place under the three neo-liberal pillars of privatization, commoditisation and deregulation (Kloppenburg, 1988; Lyson, 2002; McAfee, 2003; Roff, 2008; Salleh, 2006). It was during the recent soybean export-tax conflict in Argentina in 2008 that the clash between viewpoints regarding the country's relative position in the world's economy and its bet for trade liberalisation and export competition became more evident. The decline in the price of soybeans in late 2008 because of the world economic crisis will presumably lead to a questioning of the model of export-led growth.

In general, the neo-liberal approach to agriculture is one where the determination of the agrarian dynamics and changes is left to the free market. This is done by dumping decisions to the individual sphere (Binimelis, 2008; Cocklin et al., 2008; Devos, 2008;), and by setting self interested free choice as the only ways of safeguarding rights and liberties (Roff, 2008). The same reasoning operates regarding weed management resistance. However, the social consequences from the application of this approach to weed resistance management have been largerly under-explored. Two approaches summarize the different attitudes for managing weed resistance (Mueller et al., 2005). The first one is identified with “proactive” or “preventive” management, and includes identifying major pathways and changing environmental conditions to reduce the likelihood of future resistance, e.g. diversifying the agroecosystem, rotating crops and/or herbicides with different sites of action, or including integrated weed management strategies. The other approach is known as “reactive management”, and implies actions which aim at reducing resistance costs by changing the herbicide when no longer works; therefore, applying the most cost-efficient technology at any given time. These two strategies are also known as mitigation and adaptation, respectively (Perrings, 2005).

The dilemma about which approach to choose depends on the turning point during the decision-making process but also on the predictability of the resistance and our attitude towards uncertainty. Although a preventive strategy is usually advised (for the case of glyphosate, see e.g. Powles (2003; 2008)), farmers engaged in high-input systems are reluctant to opt for it because of short-term commercial costs and/or the inability to foresee the economic risks (Shaner, 1995). Within the reactive approach, it is assumed that novel strategies will become available when required, but also that the costs of these future strategies will not be larger than those of the present management practices. In fact, the evolution of weed herbicide resistance has neither decreased herbicide use nor incremented non-chemical practices (Beckie, 2006), but rather intensificated herbicide consumption, the so-called “herbicide treadmill”.

The aim of this paper is to analyze the driving forces behind the initial spread of GR johnsongrass and the social, economic and environmental implications of pre-emptive or reactive response strategies in the society. Reasons behind farmers’ willingness or reluctance to adopt preventive resistance management strategies are also discussed, as well as the institutional conditions and constraints. The existence of a new form of treadmill phenomenon, not only leading to the increase of herbicide use but also to the intensification in the use of GM crops will also be explored.

For doing so, this paper is structured in five sections. Following the introduction and methods, we discuss the driving forces behind the appearance of GR johnsongrass. The Argentinean agricultural system is characterized, with special focus on the GR soybean production and future scenarios. Next, the environmental history of johnsongrass and the emergence of GR biotypes are described in terms of spread, potential impacts and responses put in place. Finally, we discuss the implications of different management strategies and provide some concluding remarks.

2. Methods

There is a small but hitherto undisputed body of evidence concerning the existence of the invasion process of GR johnsongrass (Heap, 2007; Powles, 2008). In this study, we present the results of qualitative field research on actors' perceptions and understanding of the process. The qualitative techniques included semi-structured group and individual in-depth interviews and also participatory observation.

The use of these techniques is grounded on the characteristics of the case study. Complexity inherent to the invasion process and to the production system is characterised by uncertainties about the impacts related to the invasion process of GR johnsongrass. On the one hand, data regarding the degree of spread of the GR johnsongrass is incomplete due to lack of official statistics and voluntary reporting (as it will be discussed in next sections). This invalidates the analysis of impacts from a quantitative perspective. On the other hand, there are different perspectives regarding the significance of the invasion, which are better elicited through qualitative approaches (Kvale, 1996).

The informants were selected among main actors who participate in the management strategies and/or governance of the issue of GR johnsongrass. During 2007 20 semi-structured interviews were conducted in the provinces of Salta, Tucumán, Santiago del Estero, Entre Rios and Buenos Aires. These interviews aimed at eliciting the viewpoints of experts, practitioners and actors involved in the GR-johnsonsgrass conflict. Interviews were conducted with three botanists specialized in weeds, three affected farmers, two ecologists, two representatives of the main biotechnology company in Argentina, three agrarian technicians, one representative of the National Agrifood Health and Quality Service (SENASA), four scholars and researchers at private agronomy institutions and two representatives of producers' associations. The selection of actors was based on the different roles and perceptions related to the management of the GR johnsongrass (Flick, 2006; Bauer and Gaskell, 2000). The interview guide included four main aspects: a) agricultural transformations and productive dynamics on the study area; b) driving forces behind the emergence of GR johnsongrass; c) an assessment of the costs and impacts derived from the appearance of the GR johnsongrass; and d) an estimation of the GR management measures and proposals. Collected information was analyzed using ATLAS.ti, a qualitative data analysis software which allows to analyse large data sets through setting categories, systematise and refine concepts (Kelle, 2000; Lewins and Silver, 2007).

Information on the socio-economic and biological processes was collected to unravel the environmental history of the johnsongrass, the Argentinean GR soybean system and the current implications of the agronomic production model. An institutional analysis and a literature review from political economy of biotechnologies, ecological economics, agroecology, the economics of bioinvasions and weed management provided the analytical tools for tackling the GR Johnsongrass conflict.

3. The Argentinean GR soybean system

The driving forces behind the appearance of GR johnsongrass cannot be separated from the Argentina's rural development model, particularly the institutional setting and the new agrarian organization of space (i.e. the *agriculturisation* and *pampeanisation* processes). In this sense, emergence of GR johnsongrass could be seen as a foreseeable "side-effect" of this process, and its responses would be determined by the system's constraints and opportunities and also by the future productive scenarios.

3.1. Production system and technological applications

Modern Argentinean agriculture started in the late 19th century with a mixed production system (based in cattle ranching and agricultural crop rotations) which promoted an extensive low-input agronomic cropping scheme in the *Pampas* (Viglizzio et al., 2002). The *Pampas* is a vast, flat pastureland of Argentina, which covers more than 55 million hectares of arable land. However, cultivation with inappropriate tillage systems and machinery has lead to erosion. In the early 1990s, the adoption of no-till practices diminished the erosion problems but raised herbicide consumption. Non-tillage systems and soybean-wheat rotation displaced the mixed crop-cattle production system in most of the *Pampas* pastures, allowing farmers to produce three crops over a two years period. These practices also opened a window of opportunity to a range of herbicides with different modes of action in each stage of the soybean cultivation system. As a result, weed control became 40% of the input costs for farmers. By 1987, 50 chemical compounds were marketed for weed control, 22 of them for soybean fields, under several different formulations. However, only four principles comprised 60% of the market value (León et al., 1987). Fifteen companies controlled the market; of which 80% were multinational enterprises (Pengue, 2000).

The process above implied the substitution of traditional cattle production with permanent agriculture and its displacement to marginal areas or feedlots. The process of *agriculturisation*, as known in Argentina (Manuel-Navarrete et al, 2008) transfigured the mixed farming system towards an agri-industrial model. It is characterised by the diffusion of specialised mono-cultural crops, the progressive intensification of the system by the use of external inputs, the geographical separation of livestock and crops and an increasing reliance upon public, but also increasingly private, research and extension system (Marsden, 2008).

In the extra-*pampean* areas, with more complex environments, the system brings to play an increasing use of external inputs for weed and pest control. The process, called *pampeanisation*, implies the export of the technological, financial and agronomical model of the *Pampas* to other ecoregions, such as The Great Chaco or The Yungas (Pengue, 2005), hence expanding the agricultural frontier. In that sense, demand of new land increased Argentina's deforestation rates to 0,85% per year, above those found in Africa (0,78%) and above the average in South America (0,50%) (Morello and Pengue, 2007). The Department of Agriculture, Cattle Ranching, Fisheries and Food (SAGPyA, acronym in Spanish) documents a threefold increase of the cropped area between 1996/1997 and 2006/2007 sowing seasons.

The processes of *agriculturalisation* and *pampeanisation* were fostered by the introduction of the mono-cultural GR transgenic soybean model under no-tillage practices in the mid 1990s. Using glyphosate, farmers were able to control a diversity of weeds (including the most conspicuous, e.g. *Sorghum halepense, Cynodon dactylon, Cyperus rotundus* or *Chenopodium album*) at a very low cost. This allowed farmers to manage more land and increase overall productivity and profitability based on a vertical integration model (Mueller et al., 2005). In the 2006/7 campaign, 16 million hectares were sown with soy, and production reached its historical record: 48 million tones, half of the total agricultural production for Argentina (SAGPyA, 2007). Practically 100% of total soybean production is based on genetically modified GR soybeans.

3.2. The institutional setting

A series of structural reforms were necessary to favour a rapid diffusion of the technology. Government policies were among the major driving forces shifting and fitting extensive agriculture and cattle raising to the requirements of international markets. On the one hand, moving towards the *commoditisation* of the Argentinean agricultural model produced a big surplus in the current account balance, allowing the payment of the external debt interests, while increasing economic resources to maintain social plans. Exports account for most of the improvement in tax revenues and half of these taxes come from soybeans exports and its derivates (Damill et al., 2006). However, on the other hand, empowered market forces had a stronger voice in terms of strategic production decisions. Responsibilities were transferred from the state to technical NGOs and agribusiness corporations, while services such as extension usually offered by state institutions were dismantled (Manuel-Navarrete et al., 2008). It means that agricultural modernization processes and the adoption of GM technologies occurred mostly in the absence of state actors and institutions. This implied an important shift in actors concerning agrarian dynamics, development pathways and technological modernization. The active role of private actors in terms of technological diffusion and professional assistance is evidenced in strategies that are based on private sector responses. Multinational corporations become relevant actors and the major vehicle of technological modernization (Spielman, 2007).

3.3. The new social organization of space

Linked to the institutional setting, the social organization of space plays a major role as a driver in the emergence and spread of the GR-johnsongrass as well as in the adoption of response strategies. Changes in spatial patterns associated with the expansion of soybean in Argentina have been explored in detail elsewhere (Paruelo and Oesterheld, 2004). These spatial transformations associated with changes in land tenure structure are particularly relevant for the analysis of johnsongrass spread. According to the last agricultural census, units larger than 10,000 hectares have increased 13% in number and 14% in extension in *Pampas* between 1988 and 2002 (SAGPyA, 2003). Since the 1990s, there has been also an increase in land concentration in the Northern provinces of Argentina, primarily devoted to soybean production. In the Northern provinces of Salta and Santiago del Estero between 1988 and 2002 the area for agriculture increased by 70%, which means an expansion of 120,000 has per year of the agricultural frontier. About 66% of this increase is explained by increments of soybean-cultivated areas (Paruelo and Oesterheld, 2004).

New forms of land tenure favour an increasing concentration of agricultural production and management. Coinciding with findings of Kloppenburg and Geisler (1985) on the analysis of the agricultural ladder in the United States, renting land through leasing arrangements and other financial mechanisms have now come to be an advantage to achieving economic efficiency. Their findings underpin the fact that new social forms of production are no longer linked to the productive chain through ownership, but rather the system has broader objectives of net revenue and economic efficiency. In Argentina, more than 50% of the cultivated land is leased and, according to Pengue (2005), 75% of the grain in the *Pampas* is produced by large land leaseholders. Most of the leasing contracts are annual, which impose a high pressure on the land in order to obtain the maximum revenue in the shortest time. Production and management concentration facilitates the adoption of input-oriented (machinery, fertilizers, pesticides RR soybean) and process-oriented (no-tillage) systems. However, technological adoption and change are closely related to capital and information availability. While changes in production practices and adoption of GM technologies favour yield increases, Paruelo and Oesterheld (2004) have documented that beneficiaries of technological improvements are mainly large producers. For this reason, the extension of the lease regimes up to 5 years has become one of the main claims of small and medium-sized farmers (Federación Agraria, 2008)

In the case of soybean production systems, there is increasing concentration of production and management, where production processes are predominantly dominated by managerial tasks performed by a contractor (Manuel-Navarrete et al, 2008) either representing national corporate or international investment interests. According to Buzzi (quoted in Pengue (2007)) 3% of the producers concentrate 70% of the soybean production, especially under the so-called “sowing pools”. The sowing pool is a financial mechanism for soybean production. It brings together a landowner, a contractor and a technician. The economic revenue from agribusiness has been higher than in any other industrial and financial activity. The sowing pools favour agrarian capital concentration under the hands of large company contractors that lease the land to small and medium landholders. The relationship between land tenure and environmental degradation is contested. It seems evident in the extra-*Pampean* region (Manuel-Navarrete et al, 2008).

3.4. Future scenarios of the production system

In this section, we analyze the major trends for the Argentinean production system. Besides soybean seed and flour feeding the ever increasing international meat market, Argentina is also one of the greatest exporters of vegetable-oil, leading exports for soybean and sunflower derivatives. It is considered to have some of the most efficient and technologically advanced milling equipment for vegetable oil in the world, producing more than 154.000 tones per day. Strategic geographical location of the milling infrastructures at big harbours facilitates the export of 95% of this oil production (Lamers, 2006; Pengue, 2006). The sector is characterised by an industrial oligopoly, as 85% of the installed milling potential is processed by 6 companies.

Accordingly, Argentina is potentially a prime supplier for the growing biofuel industry, both for biodiesel (the raw material of which is vegetable oil from soybeans, sunflowers or canola) or bioethanol (derived from alcohols obtained from maize or sugarcane). For instance, the EU goal of 5,75% biofuel blending by 2010 would require a fivefold increase in EU production, posing a great demand for imported raw materials (APPA, 2007; Dufey, 2006; Russi, 2008). Future projections foresee biofuel production taking place mostly in developing countries, with cheap land and labour and where climatic conditions are more favourable (Wicke, 2006).

Moreover, with internal demand likely to increase due to the Argentinean “Biofuels Act” (Law 26.093), requiring 5% biodiesel content in petroleum derivates by 2010, domestic demand is estimated to reach 600.000 tonnes/year for biodiesel. At the present production rates, it is calculated that 7.3% of the soybean surface is needed for supplying this annual target of production in the first year of implementation (3,5 million tonnes of soy beans). Therefore, Argentina could not become diesel self-sufficient through soybean derived from biodiesel except if the cultivation surface is significantly increased. Although Argentinean authorities remain confident of the opportunities to increase soy yields, most of the large soybean growers, including Argentina, USA or Brazil, have apparently already optimized their production, as it has experimented little growth in last years (Johnston, 2006). International demand could press further for the expansion of the agricultural frontier. In the case of ethanol, Argentina is also one of the world’s lowest cost producers of maize. Domestic demand is estimated at around 160.000 tonnes/year for bioethanol.

4. “With the GR soybean we got to paradise… but it lasted so little…”: The emergence, impacts and responses to GR johnsongrass

4.1. Environmental history of johnsongrass in Argentina

Johnsongrass was introduced in Argentina at the beginning of the 20th century. Although it was already considered strongly invasive, the Ministry of Agriculture proposed it as a high-yield forage suitable for poor soil conditions (Estrada, 1907; Vallejo, 1913). Agronomists in Tucumán (north of Argentina) were soon alerted by its rapid, invasive potential and recommended its prohibition (Cross, 1926, 1927). By this time, land abandonment, decrease of land prices and high productivity losses were also documented (Schultz, 1931), which lead to describing the johnsongrass invasion as “the farmers’ terror” (Cross, 1934a). In 1930 it was considered a pest for agriculture in the humid and semiarid regions of the country. Although sales and imports of johnsongrass seeds and rhizomes were forbidden (de Rocha, 1930), its trade was not halted (Cross, 1934b). In 1951, sowing and multiplication were banned at the national level.

Despite these policies, by early 1980’s some estimates assert that 6 million ha of the rolling *pampas* were infested (Leguizamon, 1983), while other estimates are as high as 15 million ha, with over 94.000 affected producers (Ladelfa et al., 1983). Before that time, control techniques were either mechanical or manual, and in fact, cultivars coexisted with a wide, polyespecific weed population. During the 1970s, a series of herbicides (e.g. MSMA or Trifluralina) were introduced in the Argentinean market, and johnsongrass control techniques combined mechanical and chemical strategies. By 1977 the so-called “Plan Piloto de Salto” was launched by the National Institute of Stockbreeding Technology (INTA) in the province of Buenos Aires. Its main objective was to progressively recuperate the infested fields through implementing management techniques based on rotation practices, the use of winter cover crops and mechanical and/or chemical measures (Rossi and Cascardo, 1981). A series of empirical field trials were conducted to evaluate the efficiency of these techniques, and to improve background knowledge on the dynamics of johnsongrass (e.g. reproduction patterns, susceptibility to the temperature or to fertilisation). Costs of different management alternatives over three-year rotation periods varied between 20 and 45% of the total production costs (Cascardo and Rossi, 1979). At that time, MSMA, Dalapon, Pirifenop and glyphosate were recommended (Barletta et al., 1977). In the 1980s, the range and use of herbicides increased, both for pre-sowing herbicides and graminicides.

These methods were followed by the GR soybeans introduction, and a constant use of glyphosate apparently succeeded in controlling the weed. As said by an informant: “glyphosate becomes the essential tool for fallow-land and soybean cultivation in 1996. Johnsongrass practically disappeared from the rolling *Pampas*, except from patches on not cultivated land… but not in agricultural land”.

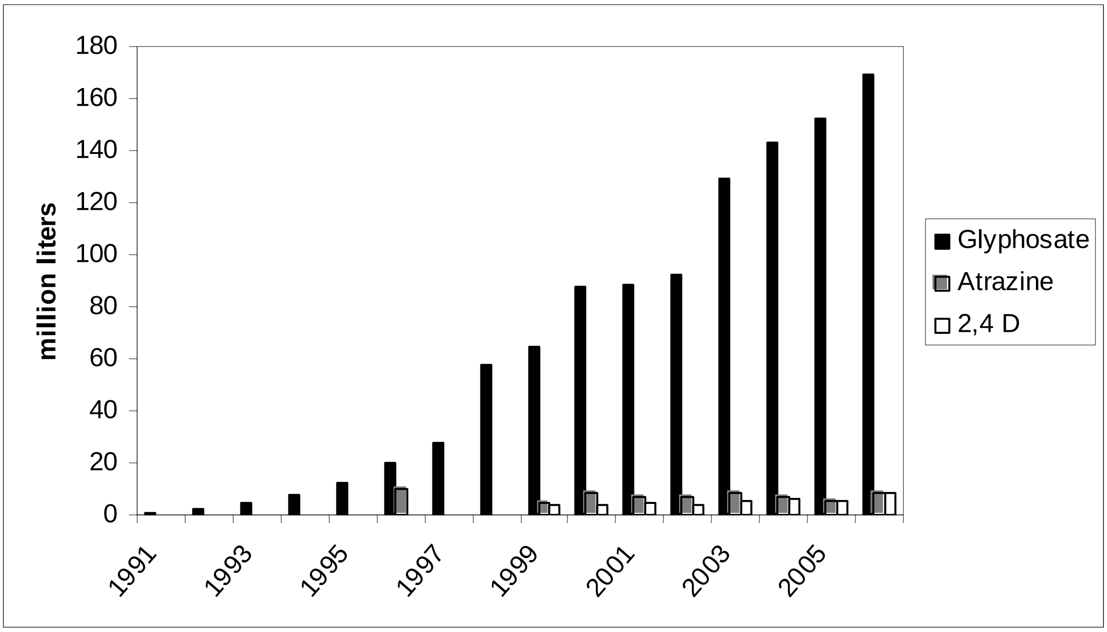
The illusion of invincibility of glyphosate to control weed species shifted emphasis toward chemical control at the expense of integrated weed management and the weed control experts groups.The soybean herbicide market was contracted. As stated by an interviewed engineer: “traditional products reduced their market presence. It is difficult to get any other product. All what is not glyphosate has to be ordered”. Others have noted that the rate of innovation in developing new herbicides has declined as agrochemical companies have acquired seed companies to produce herbicide-resistant crops. Moreover, farmers’ willingness to use other alternatives or explore weed thresholds has been reduced after GR crops adoption (Martinez-Ghersa et al., 2003; Rüegg et al., 2007). When surveying Argentinean farmers, White (1997) found that among the main motivations for adopting GR technology were better and more simplified weed control in the short term besides a decreased expenditure in herbicides, labour and fuel.

The adoption of herbicide technology in the 1960s, and glyphosate later, has been accompanied by conceptual changes in the definition of weeds and their role within the production system. For some actors, weeds may be considered an intrinsic limiting factor in the *agriculturisation* process, the economic impact of which must be minimised; while for others they are an “enemy” to be defeated when dominating nature. Amongst frequently used terms in weed management are “control”, “eradication”, “fight”, “defeat”, “wipe out”, “weapon” and the use of medical metaphors and hygienic terms such as “clean” to refer to a chemically sterilized field. All these were identified in the interviews and are examples of the mindset described above.

Glyphosate consumption became the centre of the weed management strategy, increasing sharply from 1 million litres in 1991 to 180 millions in 2007. Although glyphosate is considered a low environmental risk herbicide by some authors (Duke, 2005; Duke and Powles, 2008), others have warned that “the substitution of traditional crops [in Argentina] by GR soy in the past decades represents a large scale, unplanned, ecological experiment, whose consequences for natural ecosystems, and aquatic environments in particular, are poorly understood” (Pérez et al., 2007; see also Altieri (2004); Casabé et al. (2007); Relyea (2005)). For a discussion on human health impacts derived from glyphosate utilization in Argentina refer to Bradford (2004).

Initially after the adoption of GM soybeans the increased use of glyphosate was accompanied by a decrease in the consumption of other herbicides such as atrazine or 2,4-D. However, during the last campaigns, the consumption of these herbicides has risen again (see Figure 1). These results coincide with Bonny (2008), who concludes after assessing soybean cropping in US that the total amount of herbicides applied per ha decreased initially between 1996 and 2001, but tended to rise afterwards.

Figure 1. Evolution in glyphosate, atrazine and 2,4-D consumption in Argentina, 1996-2006.



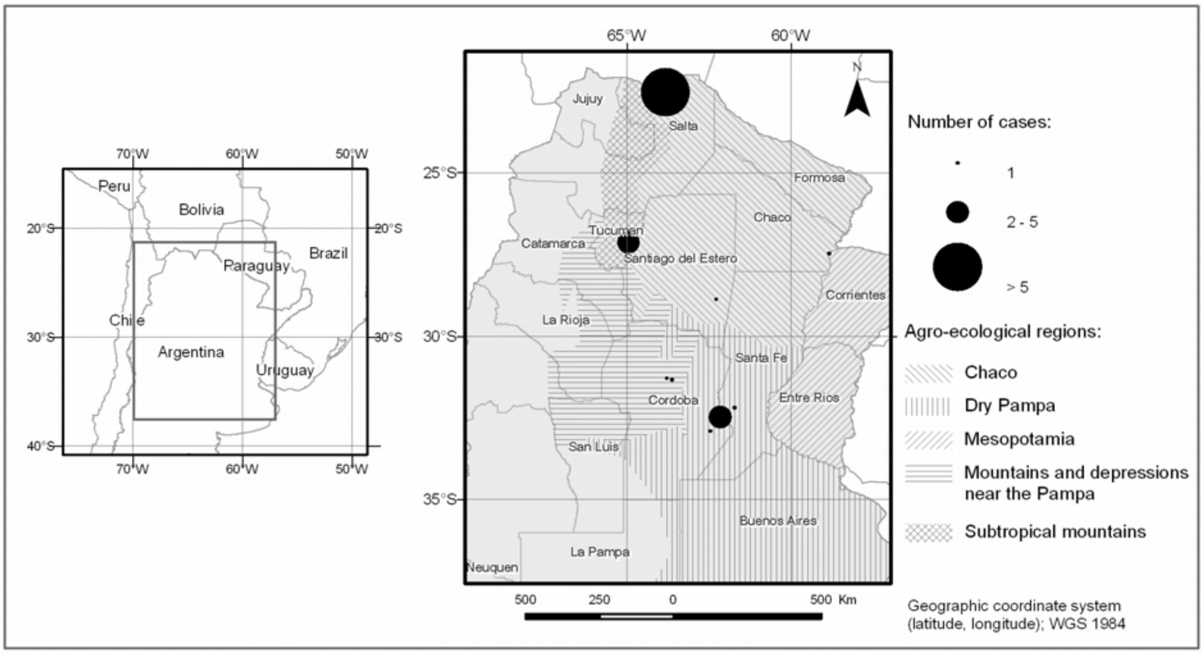
Source: Statistics have been compiled from Pengue (2000) and CASAFE (Cámara de Sanidad y Fertilizantes de la República Argentina (2007)

4.2. The emergence of GR johnsongrass biotypes in Argentina

Farmers from the province of Salta, northern Argentina, detected the appearance of a GR johnsongrass biotype in 2002. Samples were taken and brought to the USA by Monsanto in 2003. However resistance was only reported indirectly to the National Agrifood Health and Quality Service (SENASA) during a congress presentation offered by Monsanto in December 2005 (Passalacqua, 2007). The Tucumán University then confirmed it on the same year. The time lag between early detection and confirmation is commented by an affected producer: “We were losing time […] The message from all scientists, not only Monsanto’s, is that it was practically impossible to acquire resistance to glyphosate due to its site of action. Now this has changed”. At that time, different authors already warned of the potential intense selection pressure for weed resistance by genetically modified herbicide-resistant crops, that in turn jeopardize the future use of glyphosate (Owen and Zelaya, 2005; Powles, 2003; Reddy, 2001; Shaner, 2000; Snow et al., 2005; Tiedje et al., 1989; Wolfenbarger and Phifer, 2000). By 2006, eight GR weeds were already confirmed worldwide; three cases were associated with the use of herbicide-resistant crops (Cerdeira and Duke, 2006).

Although the first cases emerged in the Salta province (Valverde and Gressel, 2006), GR johnsongrass was reported in 2007 in all agroproductive provinces in northern Argentina and also in some central provinces, such as Santa Fe. It is estimated that the affected area in the north of Argentina covers 10.000 ha (Passalacqua, 2007), and our informants expected that the potential affected area might reach 100.000 ha. Figure 2, shows the GR johnsongrass' reported areas.

Figure 2: Areas with confirmed GR johnsongrass in the North and Centre of Argentina (2007)



4.3. Potential impacts associated with GR johnsongrass

Involved actors analysed differently the recent appearance and spread of the GR johnsongrass in Argentina and its implications. Most of these impacts are discussed in relation to the effects already registered in the 1930s. Again, increases in the control costs were reported in the affected fields. Implications for farmers are discussed by some informants as related to their capability to adapt to the new conditions: "this will sieve the producers. Those who are attentive will succeed; those who clean their machinery, etc… will have everything under control. The problem is with those who are still confident to manage with glyphosate. They will have problems. Other types of resistance will occur. This is the big topic". A major challenge is to replace an extremely simple weed management, based on a "fantastic technology that makes Argentina competitive worldwide" (interview, agronomist), by a more complex integrated weed management.

Yield loss and incremental control costs have induced changes in the lease regime (both in the price and length of the contract), as a consequence of the depreciation of the value of affected lands. Some stakeholders have also discussed the increase in the control costs as an added driver for the need to scale-up the economic activity, which will cause the abandonment of small and medium-sized farms or further pushing the agricultural frontier to maintain the margin of benefits. The process is similar to the one discussed by Kloppenburg (1988: 35) regarding technology adoption, in which farmers who fail to adapt to new technologies are continuously put out of business and their operations are absorbed by more successful producers, ensuring a secure and expanding market for the technology supplier.

The implementation of johnsongrass' management measures can be related to a series of socio-economic and environmental impacts. Regarding control strategies, agronomists in the affected areas suggest to return to more severe toxic, old herbicidal ingredients such as MSMA, 2,4 D and combinations of these with glyphosate in a new burn-down strategy in the no-tillage GR system, or by using rucksack equipments for a plant by plant control. Other practices have been prescribed for the containment of the GR johnsongrass, inducing further economic costs such as cleaning of agricultural machinery, or the potential rise in seeds' costs, due to purity standards. The technology advantage found by farmers in the implementation of the GR soybean in terms of cost reduction could be lost. Returning to old herbicides increases control costs drastically, leaving middle-sized farms in a dangerous situation. The increased use of MSMA or 2-4-D, with higher potential environmental and health impacts than glyphosate, or the promotion and introduction of other herbicide-resistant genetically modified seeds, will be discussed in next section.

4.4. Management responses to GR johnsongrass

Management strategies can be divided into proactive or reactive. However, this classification depends also on the stage of invasion at the decision-point. We will now review the different classes of responses and their implementation in Argentina (see Table 1).

Table 1: Responses implemented in Argentina for the management of GR johnsongrass

Before GR johnsongrass emergence	**After GR johnsongrass emergence**
Prevention	Prevention
--	--
Early detection	Early detection
--	A communication system for detection of GR johnsongrass was implemented
	Assessment
	SENASA hires an external consultancy in June 2006 for evaluating the scale of the problem and to propose management recommendations. A National Advisory Board for Resistant Pests (CONAPRE) was launched in November 2006 Two workshops were held in September 2006 and June 2007, gathering weed experts, producers and policy-makers.
	Containment
	Informative campaign launched by the Experimental Agroindustrial Station Obispo Colombres and ProGrano in 2007.
	Control
	Chemical control has been tested with several herbicides (MSMA, 2-4-D, halaxifop metil, cletodim, as well as graminicides applied locally) in soy fields.

Sources: ASAPROVE, 2006; Olea et al., 2007; Passalacqua (2007); SENASA (2007); field work interviews.

Preventive measures. In a glyphosate-based production system, preventive measures would mean to search for more diversified production, requiring a sophistication of the system as well as improving management knowledge and time. In a scenario of economic and technological optimism, no preventive measures were taken before the emergence of GR johnsongrass, nor in unaffected areas once it had already appeared in other areas of the country.

Reactive measures. Once GR johnsongrass appeared, reactive measures were implemented. These can be divided into assessment, early detection, containment or control measures (GISP, 2007). Eradication is not discussed as an option by stakeholders. It is worth mentioning that the main agricultural extensionists in charge of farmers' assessment, especially in the north of Argentina, are agronomic engineers representing private, mixed companies or private NGOs such as ProGrano (Northern Grain Producers Association) or AAPRESID (Argentinean Association of Non-Tillage Producers).

Assessment can be considered the first step of a management programme. It involves weighing the different elements within the current situation (extent of the area to be managed, determining the management goal or the stakeholders involved). Different actions were taken for assessing the state of affairs in Argentina during 2006. These are led by the proposals of an external consultancy hired by the SENASA (Valverde and Gressel, 2006). Its main recommendations include preventive measures such as putting in place early detection systems (visual and satellital), designing a public information campaign, promoting rotation schemes for avoiding or delaying the appearance of resistance, implementing measures for containment and promoting basic research and investigation on chemical control. Two workshops were held in September 2006 and June 2007 presenting and following-up this assessment, including weed experts, producers and policy-makers. A National Advisory Board for Resistant Pests (CONAPRE) was launched in November 2006 with coordination tasks (SENASA Resolution 470/2007). Its functions are similar to the ones of the first Board against Weeds created in 1936 to manage the common johnsongrass.

Early detection. SENASA has put in operation a centralised system for reporting suspected cases of GR johnsongrass. However, there has been a low number of reports. This can be linked, on the one hand, to the type of impacts that GR johnsongrass is inducing and the uncertainty on the policy consequences. It can be illustrated by some excerpts from interviews: "the reports are few because people are afraid of reporting because of getting lower rents and because they do not know how the authority is going to react, because their fields could be closed down,…"; "If a farmer has or detects GR johnsongrass, will he say it? Will he identify the problem in his field? He doesn't know what could happen because legislation is not clear: the field would be closed down? Would production be retained? What would be the cost of machinery for him? Ignorance on legislation can be a limiting factor to confront the problem […] While the problem is in the fences, it is everybody's problem, or others' problems; but when the problem is in his field, I do not know how he will react". On the other hand, the perception of the technology and the farmer itself are contested: "in general there still are […] some qualms to accept the problems. I do the comparison with some parents that deny that their son is different. They deny the problem. But it is serious. And what we have detected is that producers are reluctant to report the problem, to say it, to confess it. […] Probably there are many more cases that the ones we have detected". This situation produces a lack of data regarding the scale of the problem, but it also makes it difficult to contain it.

Containment is aimed to restrict the spread of the GR johnsongrass and to enclose the population in a defined geographical range. Again, early detection and monitoring will be a critical feature. In 2007 the Experimental Agroindustrial Station Obispo Colombres launched an information campaign on the procedures for avoiding dispersion, especially those related to machinery hygienic measures (agricultural engineer, interview). The Agroindustrial Station is a joint public-private venture. It included also information dissemination through radio and TV spots, newspapers and posters.

Control measures. Much of the effort has been directed to control measures. The objective of these is to reduce the density and abundance of the GR johnsongrass below a pre-set acceptable threshold. Control methods are usually classified as mechanical, chemical, biological, habitat management or integrated pest management (GISP, 2007). In the case of johnsongrass in Argentina, chemical methods are mainly promoted. Research is led by the main herbicide companies, in coordination with private NGOs (such as PROGRANO) who are in charge of developing the resulting strategies. In the last years, no novel herbicides with new modes of action have been introduced in the market and no quick developments are expected (Green et al., 2008). For instance, the last compound with a new mode of action –HPPD herbicide- was commercialized in Europe in 1991 (Rüegg et al., 2006). Therefore, strategies to control GR johnsongrass rely on already commercialized herbicides, either directly or through the development of novel GM crops with new herbicide-resistance characteristics, or on varieties resistant to even higher doses of glyphosate (Service, 2007).

Informants have stated that trials are conducted in Argentina aiming to control GR johnsongrass in soy fields. At the moment, the resistance mechanism is still unknown, and therefore, research for chemical control is done under a trial and error basis. These methods include the use of glyphosate mixed with MSMA, 2-4-D, cletodim or haloxifop, post-emergence graminicides (e.g. Micosulfuron, Imazethapir) or for use in fallow fields (atrazine, paraquat, 2,4 D, metsulfuron metil). They do not fully cover the complete spectrum abandoned by glyphosate, while increasing the management costs of the fields. For instance, it has been estimated that the cost of controlling GR johnsongrass with a mixture of 2,4 D and glyphosate increases production costs by 19,3% per hectare (Muñoz, 2006), apart from increased biological and human health risks. The price of the two herbicides has risen steadily since then. Other authors estimated that controlling a glyphosate resistant weed could double the herbicide expenditure per hectare in Argentina (Tuesca et al., 2007). Moreover, herbicide mixtures can inadvertently accelerate the evolution of multiple resistance if they fail to meet basic criteria for resistance management or are applied repeatedly (Beckie, 2006). However, weed control specialists remain confident: “in spite of complexity, it is possible to face and win the battle to this problem” (interview, weed management expert). On July 2007, a commercial maize variety, stacked with RoundUp resistance (i.e. GR) and Bt was released in Argentina. Rotation with RR sugarcane was also suggested by some companies. Season by season, crop by crop including fallow fields, glyphosate seems to be the unique alternative.

New GM developments in the international scenario. Biotech companies have recently launched novel GM crops with new herbicide-resistance as a response to the appearance of GR weeds (Green et al., 2008). For instance, in September 2007 DuPont and Nidera announced the glyphosate and sulfonyureas-resistant soy varieties Finesse-Sts (Ciuci, 2007). In their presentation in Argentina, the representatives of Nidera soy varieties stated: “for growing towards the future, it is required to present solutions to new problems, such as tolerance or resistance to glyphosate”. Furthermore, DuPont has developed the so-called GAT/HRA technology, which combines glyphosate and ALS resistance (including sulfonylurea and imidazolinone herbicides) for soy and maize along with other crops (Green, 2007). The technology has been commercially applied by Pioneer Hi-Bred and DuPont Crop Protection in the so-called Optimum-GAT trait, with sales anticipated within 2010-2012 (Pioneer, 2007). To date, 95 species have been reported to be ALS-resistant, including johnsongrass (Heap, 2007).

In May 2007 Monsanto and the University of Nebraska also presented the Dicamba resistant technology in the Science magazine, as a strategy to extend glyphosate effective lifetime and preserve no-till or reduced-till planting practices (Behrens et al., 2007). The technology could also be applied to soy, tobacco and cotton. Dicamba is a synthetic auxine considered as a herbicide with low toxicity, but with residuality. In a study conducted by Peterson and Hulting (2007), Dicamba was found to have higher relative risks than glyphosate for five of the nine ecological receptors evaluated. In an estimation of relative ecological risks of herbicide active ingredients made by Duke and Cerdeira (2005), Dicamba was classified as having 220 greater risks compared to glyphosate. *Kochia scoparia, Stachys arvensis* and *Galeopsis tetrahit* weeds have already been reported as Dicamba-resistant (Heap, 2007). The first two are present in Argentina. Dicamba is a selective systemic herbicide for broadleaf weeds. It is recommended that Dicamba resistance genes be used “stacked” with glyphosate resistance genes, to allow farmers to alternate between the two herbicides or mix them.

In turn, Dow AgroScience has recently presented its progress in the development of maize and soy varieties resistant to 2,4 D, “fop” grass herbicides and insects (Dow AgroSciences, 2007a). Although offered as a herbicide with few resistant weed populations, resistance to 2,4 D has been registered in 16 weed plant species. First records already date from 1952 (Heap, 2007). The company expects to commercialize the GM maize in 2012/3 or 2014 for soybeans. As stated in a company press release, this technology comes after foreseeing GR weeds, so the purpose is that it can be coupled with current available herbicide tolerant traits.

In maize production, Dow and Monsanto companies have recently presented a genetically modified maize, in which eight genes are stacked for herbicide tolerance and insect-protection. It has been published as the "'all-in-one' answer to demands for a comprehensive yield protection from weed and insect traits" (Dow AgroSciences, 2007b). The new GM crop –SmartStax- is expected to be commercialised in the U.S. by the end of the decade, combining glyphosate and ammonium glufosinate resistance with corn worm protection.

Finally, research has also been conducted to obtain glyphosate-tolerant maize with higher resistance to the herbicide. Athenix Corp, for instance, expects to submit a regulatory package by the end of 2008 in the USA for maize capable of withstanding at least eight times the standard field rate of glyphosate recommended, providing "the highest levels of glyphosate tolerance available" (Athenix Corp., 2007). Field trials for soybean are about to begin.

5. Discussion and concluding remarks

In this section we analyse the responses for the management of GR johnsongrass in Argentina and their implications. The process of *agriculturalisation* in the rolling *Pampas* that began in the mid 1970s, and the subsequent *pampeanisation* of extra-Pampean regions have meant a strong intensification of the productive system. This was possible through the representation of Argentina as an "almost unlimited" land (Garavaglia, 1989), metaphorically described as a desert that could be transformed for production through the submission of the environment (Pengue, 2003) and the local populations (Navarro Floria, 1999). Although these material and mental processes started in Argentina long ago, they played a central role in the massive diffusion of soybean production in recent years, which was also supported by a series of institutions (e.g. increasing offers of credits for investments in phytosanitary control, especially herbicides during the 1970s (León et al., 1987)) and innovations in land tenure arrangements. With the introduction of the GR technology package, intensification became the sole productive alternative under the efficiency paradigm (Pengue, 2004).

In these processes, weed management was identified as the bottleneck for the production model, and great economic and labour efforts were devoted to weed control. As the example of johnsongrass illustrates, the “magic bullet” approach was favoured. As discussed by Scott (2005), this term was firstly coined in biomedicine for referring to a model centred in the agent as “the” cause of disease. In integrated pest management literature it is argued that the approach has been similarly applied to weed management (Buhler et al., 2000; Hoy, 1998; Neve, 2007; Scott, 2005). Synthetic herbicides are aimed to react once the pest has appeared. However, this is usually done without analysing ecological and evolutionary dynamics of the site, as well as the social conditions of application (ibid). This approach has also been discussed in the context of herbicide-resistant GMOs (Altieri, 2005; Altieri and Rosset, 1999; Appleby, 2005; McAfee, 2003; Mueller-Schaerer, 2002).

As a consequence of the approach, all pests become targets per se (Prokopy, 1987). In that sense, weed control has been equated to weed-free, and field appearance becomes then a major motivation for weed control (Jones and Medd, 2000). This notion could also partly explain the increasing glyphosate consumption in Argentina (besides the increment of area sown with soybeans). As single post-emergence application is insufficient to reach total weed control, repeated applications are needed. This approach has been metaphorically identified by critics of GM technology as the “green concrete”, as no other plant, except the crop, can grow (Levidow and Carr, 2007). However, from an economic point of view, the optimum level of weed control may be less than 100% unless if it is assumed that the crop is infinitely valuable or control costs are zero (Martínez-Ghersa et al., 2003).

The golden moment for soybean production has reinforced this approach. In 2007 and until July 2008, the historical records for soybean yield and price were reached, in part due to the sharply escalating biofuels demand, giving support to the technological optimism driving agricultural shifts in Argentina. However, the GR technology may be judged as a technological lock-in, discouraging the adoption of weed-resistance preventive measures and unable to cope with GR weeds. As this case study shows, Argentinean farmers were deskilled at an extraordinary speed, becoming weed “illiterates” while forgetting early attempts to integrate pest management. In that sense, literature on path dependency has pointed out the fact that dynamic increasing returns imply that, once chosen, a technology path has the tendency to be stretched. Results from our case study coincide with the findings of Cowan and Gunley (1996), who have argued that three aspects determine the low rate of adoption of integrated pest management as an alternative to chemical management: a) initial low payoff for this technology, as the necessary knowledge is not available; b) uncertainty on the outcomes; and c) “coordination” problems among farmers, in terms of the effects that neighbouring practices have on their own fields. All these factors were fostered in this case by the “glyphosate dependence”.

Despite these collective facts, recommendations generally assume that the management strategy of an individual farmer shapes the future incidence of herbicide-resistant weeds in his/her fields (see e.g. Dill et al., 2008). However, as weeds act as a common factor (Regev et al., 1976), appearance of herbicide-resistant weeds, or their control, depend on the weakest point of the system, i.e. the least effective farmer. The scale would depend on the potential range of spread by the weed (Perrings et al., 2002). As a result, from an individual farmer's point of view, investing in preventing the emergence of herbicide-resistant populations in a field, might not capture the future benefits of having avoided the costs of managing the herbicide-resistant weed (Llewellyn and Allen, 2006), especially in a situation of annual lease regimes. If the necessary cooperation between farmers is not enhanced, only adaptation or reactive measures can be taken. In a highly competitive context, preventive management needs an institutional setting that establishes regulations and responsibilities.

From a societal point of view, reactive measures would favour those with the resources to adapt to the fact while on the other hand, risks are transferred to society and the environment (Perrings, 2005). Mueller et al. (2005) argue that glyphosate in conjunction with GR crops allows farmers to manage more hectares and increase overall productivity and profitability. However, it raises equity concerns, in particularly those related to access to resources and finances. For instance, from the analysis on the emergence of GR johnsongrass in Argentina, it can be argued that small and medium-sized farmers are those left in worse positions to overcome the situation. Having small plots makes them more vulnerable to the neighbouring effect. Moreover, the economic structure disincentives the farmers to invest in uncertain alternative practices, which require long-term planning or restructuring time. The environmental history of johnsongrass in Argentina shows that when it was not possible to control this weed, farmers directly abandoned the land or sold it. At the same time, herbicide companies have found a new market niche.

As a result of the intensification of the agricultural model, the appearance of GR johnsongrass becomes a driver for further concentration while opening new markets for technology suppliers. In the case of glyphosate, whose patent has expired, gene stacking is particularly profitable as it increases the value of the seeds by including two or more technological fees rather than just one (Bonny, 2008). Proposed strategies to deal with the situation are focused on reactive measures, potentially causing a series of externalities. Impacts of the potential increment of herbicide use on human health and the environment should be further analysed. The chemical option is again the keystone of the strategy. Since new herbicide developments seem to be in a deadlock, existing options within the paradigm go to add one of the available herbicides to the glyphosate technological package, either directly or by massively incorporating the technology through the seed. In that sense, although aiming to overcome the effects of the "previous" GR crop generation, this "new generation" of GM crops strengthens the same paradigm. As a new magic bullet, this process may represent a new form of herbicide intensification: the "transgenic treadmill".

Acknowledgements

This study is part of the EU-funded research project ALARM (Assessing LArge-scale environmental Risks for biodiversity with tested Methods. We are grateful to James Klepek, Nicolas Kosoy, Joan Martinez Alier and Roger Strand for their comments on early versions of the article. We are particularly grateful to all the stakeholders who collaborated in the research process.

References

Altieri, M.A., Rosset, P., 1999. Ten reasons why biotechnology will not ensure food security, protect the environment and reduce poverty in the developing world. AgBioForum 2 (3/4), 155-162.

Altieri, M.A., 2004. Genetic engineering in agriculture: the myths, environmental risks and alternatives. Food First Books, Oakland.

Altieri, M.A., 2005. The myth of coexistence: Why transgenic crops are not compatible with agroecologically based systems of production. Bulletin of Science, Technology & Society 25 (4), 361-371.

APPA, 2007. Biocarburantes y Desarrollo Sostenible. Mitos y Realidades, Madrid. <http://www.appa.es/descargas/Doc_BIOCARBURANTES_1309.pdf>.

Appleby, A.P., 2005. A history of weed control in the United States and Canada -a sequel. Weed Science 53, 762–768.

ASAPROVE, 2006. Taller dinámica de la resistencia a herbicidas: caso sorgo de alepo. ASAPROVE Bulletin 25, 6-8.

Athenix Corp., 2007. New glyphosate-tolerant corn from Athenix demonstrates superior performance. Press release, 14th August. <www.athenixcorp.news_081407.html>.

Barletta, U., Arregui, C., Mitidieri, A., 1977. Sorgo de Alepo. Cartilla de extensión, 3. Información para extensión. INTA.

Barton, J.E., Dracup, M., 2000. Genetically Modified Crops and the Environment. Agronomic Journal 92, 797–803.

Bauer, M.W., Gaskell, G. (Eds) Qualitative Researching with Text, Image and Sound. Sage, London.

Beckie, H.J., 2006. Herbicide-resistant weeds: management tactics and practices. Weed Technology 20, 793-814.

Behrens, M.R., Mutlu, N., Chakraborty, S., Dumitru, R., Jiang, W.Z., LaVallee, B.,J., Herman, P.L., Clemente, T.E., Weeks, D.P., 2007. Dicamba resistance: enlarging and preserving biotechnology-based weed management strategies. Science 326, 1185-1188.

Binimelis, R., 2008. Coexistence of plants, coexistence of farmers. Is an individual choice possible? Journal of Agricultural and Environmental Ethics 21, 437-457.

Bonny, S., 2008. Genetically modified glyphosate-tolerant soybean in the USA: adoption factors, impacts and prospects. A review. Agronomy for Sustainable Development 28, 21–32.

Bradford, S., 2004. Argentina's Bitter Harvest: What GM Soya Has Done for Argentina. New Scientist, 2443. 17th April.

Bradshaw, L.D., Padgette, S.R., Kimballs, S.L., Wells, B.H., 1997. Perspectives on glyphosate resistance. Weed Technology 11 (1), 189-198.

Bridge, G., McManus, P., Marsden, T., 2003. The next new thing? Biotechnology and its discontents. Geoforum 34, 165-174.

Buhler, D.D., Matt Liebman, M., Obrycki, J.J., 2000. Theoretical and practical challenges to an IPM approach to weed management. Weed Science 48, 274–280.

Buttel, F.H., Barker, R., 1985. Emerging agricultural technologies, public policy, and implications for Third World Agriculture: The case of biotechnology. American Journal of Agricultural Economics 67 (5), 1170-1175.

Buttel, F.H., Kenney, M., Kloppenburg, J.Jr., 1985. From Green Revolution to Biorevolution: some observations on the changing economic bases of economic transformation in the Third World. Economic Development and Cultural Change 34 (1), 31-55.

CASAFE, 2007. Cámara Argentina de Sanidad y Fertilizantes. Estadística. <http://www.casafe.org/mediciondemercado.html>.

Cascardo, A.R., Rossi, R., 1979. Control de sorgo de alepo: Evaluación económica de distintas alternativas. Plan Piloto Salto. INTA, Evaluación económica 9, 1-13.

Casabé, N., Piola, L., Fuchs, J., Oneto, M.L., Pamparato, L., Basack, S., Giménez, R., Massaro, R., Papa, J., Kersten, E., 2007. Ecotoxicological Assessment of the Effects of Glyphosate and Chlorpyrifos in an Argentine Soya Field. Journal of Soils and Sediments 7 (4), 232-239.

Cerdeira, A.L., Duke, S.O., 2006. The current status and environmental impacts of GR crops: A review. Journal of Environmental Quality 35, 1633-1658.

Ciuci, L., 2007. Un nuevo hito en la innovación tecnológica. La Nación, 15th September. <https://www.niderasemillas.com.ar/>.

Cocklin, C., Dibden, J., Gibbs, D., 2008. Competitiveness versus “clean and green”? The regulation and governance of GMOs in Australia and the UK. Geoforum 39, 161-173.

Cowan, R. and Gunley, P., 1996. Sprayed to death: Path dependence, lock-in and pest control strategies. The Economic Journal 106 (436), 521-542.

Cross, W.E., 1926. La extirpación del pasto ruso (“*Sorghum halepense*”). Revista Industrial y Agrícola de Tucumán XVI, 71.

Cross, W.E., 1927. Sobre plagas agrícolas. Nota al Ministro de Agricultura de la Nación. Revista Industrial y Agrícola de Tucumán XVII, 261-263.

Cross, W.E., 1934a. La estación experimental agrícola de Tucumán en la lucha contra el sorgo de alepo (pasto ruso). Revista Industrial y Agrícola de Tucumán XXIV (9/10), 181-183.

Cross, W.E., 1934b. La extirpación del sorgo de alepo. Revista Industrial y Agrícola de Tucumán XXIV (9/10), 184-195.

Damill, M., Frenkel, R., Rapetti, M., 2006. The Argentinean debt: history, default and restructuring. Desarrollo Económico (Buenos Aires), [online] 1, special section.

De Rocha, A., 1930. Decretos reglamentarios de leyes nacionales. La Facultad, Buenos Aires.

Devos, Y., Maeseele, P., Reheul, D., Vanspeybroeck, L., de Waele, D., 2008. Ethics in the societal debate on genetically modified organisms: a (re)quest for sense and sensibility. Journal of Agricultural and Environmental Ethics 21 (1): 29-61.

Dill, G.M., CaJacob, C.A., Padgette, S.R., 2008. Glyphosate-resistant crops: adoption, use and future considerations. Pest Management Science 64, 326–331.

Dow AgroSciences, 2007a. Dow AgroSciences reveals progress on new herbicide tolerant trait. Dow AgroScience News Room, 28th August.

Dow AgroSciences, 2007b. Monsanto, Dow Agreement paves the way for industry's first-ever, eight-gene stacked offering in corn. Dow AgroScience News Room, 14th September.

Dufey, A., 2006. Biofuels production, trade and sustainable development: emerging issues. International Institute for Environment and Development (IIED), London.

Duke, S.O., 2005. Taking stock of herbicide-resistant crops ten years after introduction. Pest Management Science 61, 211–218.

Duke, S.O., Cerdeira, A.L., 2005. Potential environmental impacts of herbicide-resistant crops. Collection of Biosafety Reviews 2, 66-143.

Duke, S.O., Powles, S.B., 2008 Glyphosate: a once-in-a-century herbicide. Pest Management Science 64, 319–325.

Ervin, D.E., Welsh, R., Batie , S.S., Carpentier, C.H., 2003. Towards an ecological systems approach in public research for environmental regulation of transgenic crops. Agriculture, Ecosystems and Environment 99, 1–14.

Estrada, M., 1907. Pastos de verano y pastos de invierno. Forrajes intercalados. Agriculture Ministry Bulletin VIII (1-2), 87-100.

FAO database, 2007. *Sorghum halepense* (L.) Pers. Plant production and protection division. Integrated Pest Management- Weed Management. <http://www.fao.org/ag/agp/agpp/ipm/Weeds. Accessed 28th October 2007>.

Federación Agraria, 2008. El congreso discute el futuro de las políticas agropecuarias. Press release, 27th June <http://www.faa.com.ar/>.

Flick, U., 2006. An Introduction to Qualitative Research. 3rd Edition. Sage, London.

Garavaglia, J.C., 1989. Ecosistemas y tecnología agraria: Elementos para una historia social de los ecosistemas rioplatenses (1700-1830). Desarrollo Económico 28 (112), 549-575.

Gibbs, D., Cocklin, C., Dibden, J., 2008. Genetically modified organisms (GMOs) and the future of rural spaces. Geoforum 39, 145-147.

GISP, 2007. Ecology and Management of Invasive Alien Species: Management. <http://www.gisp.org/ecology/>.

Green, J.M., 2007. Review of glyphosate and ALS-inhibiting herbicide crop resistance and resistant weed management. Weed Technology 21, 547-558.

Green, J.M., Hazel, C.B., Forney, D.R., Pugh, L.M., 2008. New multiple-herbicide crop resistance and formulation technology to augment the utility of glyphosate. Pest Management Science 64 (4), 332–339.

Heap, I.M., 2007. International survey of herbicide resistant weeds. <http://www.weedscience.org>.

Herrick, C.B., 2005. 'Cultures of GM': discourses of risk and labelling of GMOs in the UK and EU. Area 37 (3), 286–294.

Hoy, M.A., 1998. Myths, models and mitigation of resistance to pesticides. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 353, 1787-1795.

Johnston, M., 2006. Evaluating the Potential for Large-Scale Biodiesel Deployments in a Global Context. MSc University of Wisconsin-Madison.

Jones, R.E., Medd, R.W., 2000. Economic Thresholds and the Case for Longer Term Approaches to Population Management of Weeds. Weed Technology 14, 337–350.

Kelle, U., 2000. Computer-assisted analysis: coding and indexing. In: Bauer, M.W., Gaskell, G. (Eds.) Qualitative Researching with Text, Image and Sound. Sage, London, pp. 282-298.

Kloppenburg, J.R., Geisler, C., 1985. The Agricultural Ladder: Agrarian Ideology and the Changing Structure of U.S. Agriculture. Journal of Rural Studies 1 (1), 59-72.

Kloppenburg, J.R., 1988. First the seed. The political economy of plant biotechnology, 1492-2000. Cambridge University Press, Cambridge.

Kvale, S., 1996. InterViews. An Introduction to Qualitative Research Interviewing. Sage, Thousand Oaks.

Ladelfa, A., Lavezzari, D., Moris, N., Silla, R., Núñez, A., 1983. Control de sorgo de alepo en soja. INTA, Pergamino.

Lamers, P., 2006. Emerging liquid biofuel markets, ¿A dónde va la Argentina? MSc in Environmental Management and Policy. IIIEE, Lund.

Leguizamón, E., 1983. Población dinámica. El sorgo de alepo en la secuencia trigo/soja. Desarrollo rural 24, 76-79.

León, C., D'Amato, L., Iturregui, M.A., 1987. El mercado de plaguicidas en la Argentina. Desarrollo Económico 27 (105), 129-144.

Levidow, L., Boschert, K., 2008. Coexistence or contradiction? GM crops versus alternative agricultures in Europe. Geoforum 39 (1), 174-90.

Levidow, L., Carr, S., 2007. GM crops on trial: Technological development as a real-world experiment. Futures 39, 408–431.

Lewins, A., Silver, C., 2007. Using software in Qualitative Research. Sage, London.

Llewellyn, R.S., Allen, D.M., 2006. Expected mobility of herbicide resistance via weed seeds and pollen in a Western Australian cropping region. Crop Protection 25, 520-526.

Lyons, K., Lawrence, G., 1999. Alternative Knowledges, Organic Agriculture, and the Biotechnology Debate. Culture & Agriculture 21 (2), 1-12.

Lyson, T.A., 2002. Advanced agricultural biotechnologies and sustainable agriculture. Trends in Biotechnology 20 (4), 193-196.

Manuel-Navarrete, D., Gallopín, G., Blanco, M., Díaz Zorita, M., Ferraro, D., Herzer, H., Laterra, P., Morello, J., Murmis, M.R., Pengue, W., Piñeiro, M., Podestá, G., Satorre, E.H., Torrent, M., Torres, F., Viglizzo, E., Caputo, M.G., Celis, A., 2005. Análisis sistémico de la agriculturalización en la pampa húmeda argentina y sus consecuencias en regiones extrapampeanas: sostenibilidad, brechas de conocimiento e integración de políticas. Serie Medio Ambiente y Desarrollo 118. CEPAL. Santiago de Chile.

Marsden, T., 2008. Agri-food contestations in rural space: GM in its regulatory context. Geoforum 39, 191–203

Martínez-Ghersa, M.A., Worster, C.A., Radosevich, S.R., 2003. Concerns a Weed Scientist Might Have About Herbicide-Tolerant Crops: A Revisitation. Weed Technology 17, 202–210.

McAfee, K., 2003. Neoliberalism on the molecular scale. Economic and genetic reductionism in biotechnology battles. Geoforum 34, 203-219.

McAfee, K., 2008. Beyond techno-science: Transgenic maize in the fight over Mexico's future. Geoforum 39, 148–160.

Monsanto, 2008. Glyphosate Resistant Johnsongrass Confirmed In Two Locations. Press release 12th March. Available at: <http://monsanto.mediaroom.com/index.php?s=43&item=580>

Morello, J., Pengue, W.A. 2007. Manifiesto contra la deforestacion. Notícias, Buenos Aires. <http://www.revista-noticias.com.ar/comun/nota.php?art=640&ed=1599>

Mueller, T.C., Mitchell, P.D., Young, B.G.. Culpepper, S., 2005. Proactive versus reactive management of GR or –tolerant weeds. Weed Technology 19, 924-933.

Mueller-Schaerer, H., 2002. Principles of Integrated Pest Management with Emphasis on Weeds. Encyclopedia of Pest Management, 1-4.

Muñoz, R., 2006. Implicancias económicas para la agricultura Argentina. Paper presented at the conference "Dinámica de resistencia a herbicidas. Caso sorgo de alepo", Argentina.

Navarro Floria, P., 1999. Un país sin indios. La imagen de la Pampa y la Patagonia en la geografía del naciente estado argentino. Scripta Nova. Revista Electrónica de Geografía y Ciencias Sociales, 51 <www.ub.es/geocrit/sn-51.htm>.

Neve, P., 2007. Challenges for herbicide resistance evolution and management: 50 years after Harper. Weed Research 47, 365–369.

Olea, I.L., Vinciguerra, H.F., Raimondo, J., Sabaté, S., Rodríguez, W.A., 2007. Sorgo de alepo resistente al glifosato. Recomendaciones para prevenir su diseminación. Gacetilla Agroindustrial, 70. Estación Experimental Obispo Columbres <www.eeaoc.org.ar>.

Owen, M.D.K, Zelaya, I.A., 2005. Herbicide-resistant crops and weed resistance to herbicides. Pest Management Science 61, 301-311.

Papa, J. 2000. Malezas tolerantes que pueden afectar el cultivo de soja [Tolerant weeds that can affect the soybean crop]. National Institute of Agricultural Research [INTA], Santa Fe Regional Center, Extension Agency Oliveros.

Paruelo, J.M., Oesterheld, M. 2004. Patrones espaciales y temporales de la expansión de la soja en Argentina. Relación con factores socio-económicos y ambientales. Agronomy Faculty, Universidad de Buenos Aires. <http://www.agro.uba.ar/users/lart/bancomundial/INFORME_final.pdf>

Passalacqua, S.A., 2007. El rol del estado en la problemática de plagas resistentes: "Caso sorgo de alepo resistente al herbicida glifosato". Round Table AAPRESID Congress, 16th August.

Pengue, W.A., 2000. Cultivos Transgénicos ¿Hacia dónde vamos?. UNESCO. Lugar Editorial. Buenos Aires.

Pengue, W.A., 2003. El glifosato y la dominación del ambiente. Biodiversidad, Sustento y Cultura 37, 1-7.

Pengue, W.A., 2004. Producción agroexportadora e (in)seguridad alimentaria: El caso de la soja en Argentina. Revista Iberoamericana de Economía Ecológica 1, 30-40.

Pengue, W.A., 2005. Agricultura industrial y agricultura familiar en el MERCOSUR. El pez grande se come al chico… ¿siempre? Le Monde Diplomatique, edición Cono Sur 71, 7-9.

Pengue, W.A., 2006. Modelo Agroexportador, Hidrovía Paraguay Paraná y sus Consecuencias Socioambientales. ¿Una compleja integración para América Latina?. Un enfoque desde la Economía Ecológica y el Análisis Multicriterial. Coalición Rios Vivos. Rosario. Santa Fe.

Pengue, W.A. 2007. Cuando tenga la tierra. Le Monde Diplomatique, edición Cono Sur 94, 10.

Pérez, G.L., Torremorell, A., Mugni, H., Rodríguez, P., Solange Vera, M., Do Nacimiento, M., Allende, L., Bustingorry, J., Escaray, R., Ferraro., M., Izaguirre, I., Pizarro, H., Bonetto, C., Morris, D.P., Zagarese, H., 2007. Effects of the herbicide RoundUp on freshwater microbial communities: a mesocosm study. Ecological Applications 17 (8), 2310–2322.

Perrings, C., 2005. Mitigation and adaptation strategies for the control of biological invasions. Ecological Economics 52 (3), 315-325.

Perrings, C., Williamson, M., Barbier, E. B., Delfino, D., Dalmazzone, S., Shogren, J., Simmons, P., Watkinson, A., 2002. Biological invasion risks and the public good: an economic perspective. Conservation Ecology 6(1): 1. [online] <http://www.consecol.org/vol6/iss1/art1>.

Peterson, R.K.D., Hulting, A.G., 2004. A comparative ecological risk assessment for herbicides used on spring wheat: the effect of glyphosate when used within a glyphosate-tolerant wheat system. Weed Science 52, 834-844.

Pioneer, 2007. Optimum™ and GAT™ Trait: new glyphosate and ALS-tolerance technology. Press Release, 17th August.

Powles, S. B., 2003. My view. Weed Science 51, 471.

Powles, S.B., 2008. Evolved glyphosate-resistant weeds around the world: lessons to be learnt. Pest Management Science 64 (4), 360-365.

Prokopy, R.J. 1987. Review: Holistic Pest Management. Reviewed Work: Ecological Theory and Integrated Pest Management Practice by Marcos Kogan. Science 238 (4825), 410-411.

Regev, U., Gutiérrez, A.P., Feder, G., 1976. Pests as a Common Property Resource: A Case Study of Alfalfa Weevil Control. American Journal of Agricultural Economics 58 (2), 186-197.

Reddy, K.N., 2001. GR soybean as a weed management tool: opportunities and challenges. Weed Biology and Management 1, 193-2002.

Relyea, R.A., 2005. The lethal impact of RoundUp on aquatic and terrestrial amphibians. Ecological Applications 15 (4), 1118–1124.

Roff, R.J., 2008. Preempting to nothing: neoliberalism and the fight to de/re-regulate agricultural biotechnology, Geoforum 39, 1423–1438.

Rossi, A.R., Cascardo, A., R., 1981. Plan piloto de Salto. Carpeta de producción vegetal, Generalidades. Información 33. INTA, Pergamino.

Rüegg, W.T., Quadranti, M., Zoschke, A., 2007. Herbicide research and development: challenges and opportunities. Weed Research 47, 271–275.

Russi, D., 2008. An integrated assessment of a large-scale biodiesel production in Italy: Killing several birds with one stone? Energy Policy 36 (3), 1169-1180.

SAGPyA., 2003. Resultados Definitivos del Censo Nacional Agropecuario 2002. Secretaría de Agricultura, Ganadería, Pesca y Alimentos. Subsecretaría de Economía Agropecuaria. Dirección de Economía Agraria. <http://www.sagpya.mecon.gov.ar/new/0-0/programas/economia_agraria/index/censo/Parte_I.pdf>

SAGPyA., 2007. Estimaciones agrícolas mensuales. Cifras oficiales al 17/09/07. <www.sagpya.mecon.gov.ar>.

Salleh, A., 2006. “Organised irresponsibility”: Contradictions in the Australian government’s strategy for GM regulation. Environmental Politics 15 (3): 399-416.

Schultz, E.F., 1931. La exterminación del “pasto ruso” o “sorgo de alepo”. Revista Industrial y Agrícola de Tucumán, XXI: 200-202.

Scott, D., 2005. The magic bullet criticism of agricultural biotechnology. Journal of Agricultural and Environmental Ethics 18, 259–267.

SENASA, 2007. Resolución 470/2007. Crea en el ámbito de la Dirección Nacional de Protección Vegetal dependiente de este Servicio Nacional, la Comisión Nacional Asesora sobre Plagas Resistentes (CONAPRE), 3rd August.

Service, R.F., 2007. A growing threat down on the farm. Science 316, 1114-1117.

Shaner, D.L., 1995. Herbicide Resistance: Where are we? How did we get here? Where are we going? Weed Technology 9, 850-856.

Shaner, D.L., 2000. The impact of glyphosate-tolerant crops on the use of other herbicides and on resistance management. Pest Management Science 56, 320-326.

Snow, A.A., Andow, D.A., Gepts, P., Hallerman, E.M., Power, A., Tiedje, J.M., Wolfenbarger, L.L., 2005. Genetically engineered organisms and the environment: current status and recommendations. Ecological Applications 15 (2), 377-404.

Spielman, D.J. 2007. Pro-poor agricultural biotechnology: Can international research system deliver the goods? Food Policy 32, 189-204.

Steinbrecher, R.A., 2001. Ecological consequences of genetic engineering. In Tokar, B., (Ed.) Redesinging life? The worldwide challenge to genetic engineering. Zed Books, London, pp. 75-102.

Tiedje, J.M., Colwell, R.K., Grossman, Y.L., Hodson, R.E., Lenski, R.E., Mack, R.N., Regal, P.J., 1989. The planned introduction of Genetically Engineered Organisms: Ecological considerations and recommendations. Ecology 70 (2), 298-315.

Tuesca, D. Nisensohn, L, Papa, J.C. 2007. Para estar alerta: El sorgo de alepo (*Sorghum halepense*) resistente al glifosato. INTA, <http://www.inta.gov.ar/region/sf/proteccion_vegetal/alertas/2007-11-sorgo-alepo-sorghum-halepense-resistente-a-glifosato.pdf>.

Vallejo, S., 1913. A propósito del cultivo del "*Sorghum alepensis*" como forraje. Agriculture Ministry Bulletin XV (1), 94-99.

Valverde, B.E., 2007. Status and Management of Grass-Weed Herbicide Resistance in Latin America. Weed Technology 21, 310–323.

Valverde, B.E., Gressel. J., 2006. Dealing with the Evolution and Spread of *Sorghum* halepense glyphosate resistance in Argentina. Consultancy report to SENASA. <www.sinavimo.gov.ar/files/senasareport2006.pdf>.

Verhoog, H., 2007. Organic agriculture versus genetic engineering. Netherlands Journal of Agricultural Science 54 (4), 387–400.

Viglizzo, E., Pordomingo, A., Castro, M., Lectora, F., 2002. La sustentabilidad ambiental del agro pampeano. Ediciones INTA. Instituto Nacional de Tecnología Agropecuaria, Buenos Aires.

White, D. 1997. Actitud del sector agropecuario argentino ante la biotecnologia agrícola. 4° Seminario de Actualización Técnica en Biotecnología Agrícola. CPIA, Buenos Aires.

Wicke, B., 2006. The Socio-Economic Impacts of Large-Scale Land Use Change and Export-Oriented Bio-Energy Production in Argentina. MSc Copernicus Institute, Utrecht.

Wolfenbarger, L.L., Phifer, P.R., 2000. The ecological risks and benefits of genetically engineered plants. Science 290, 2088-2093.

Woodburn, A.T., 2000. Glyphosate: production, pricing and use worldwide. Pest Management Science 56, 309-312.

Acknowledgements / Agraïments

Mentre estava fent aquesta tesis, he tingut la immensa sort de comptar amb l'ajuda i el suport de moltíssima gent.

A banda dels agraïments "individualitzats" que es troben a cadascun dels articles, en primer lloc, voldria agrair a Joan Martínez Alier la confiança que des de fa ja molts anys sempre ha dipositat amb mi, i amb el meu treball. D'ell vaig aprendre, ja fa temps, quan començava la meva llicenciatura en Ciències Ambientals, què és l'economia ecològica i l'ecologia política i d'ell continuo aprenent cada dia.

Igualment, vull agrair al meu co-director, Roger Strand, el seu suport. Roger sempre ha estat sempre constructiu en les seves crítiques i generós en la seva dedicació. Així mateix, m'agradaria agrair-li, un cop més, les seves nombroses acollides a Noruega, gràcies a les quals he pogut trobar l'ambient necessari (tan intel·lectual com físic) per poder acabar aquesta tesis. M'agradaria aprofitar aquesta oportunitat per donar les gràcies a la Kamilla, Fern, Kjetil i Ana a Bergen, que em van recolzar especialment durant els mesos que vaig passar allí.

També crucial ha estat la meva col·laboració durant els darrers quatre anys amb les meves amigues i companyes al projecte ALARM Iliana Monterroso i Beatriz Rodríguez-Labajos, amb qui he tingut el plaer de treballar i viatjar durant tot aquest temps. La realització d'aquest treball tesis no hagués estat possible sense elles.

Així mateix, han estat de gran utilitat les discussions i treball conjunt realitzat amb la resta de membres del grup socio-econòmic de l'ALARM. Vull donar gràcies especialment a Walter Pengue a Argentina, i també a totes aquelles persones i col·lectius que han participat, aportant el seu coneixement i visions als diferents conflictes ambientals que s'estudien durant aquesta tesis. Sense elles aquesta tesis no tindria sentit.

També voldria agrair als meus companys i companyes de l'ICTA el seu afecte i encoratjament durant tot aquest temps; així com a les meves amigues i amics (no els anomeno per por de deixar-me'n algun/a). M'agradaria fer una menció especial a la gent de Cal Cases. He tingut també la sort de comptar amb el meu amic Nicolas Kosoy en nombroses ocasions, per discutir els articles o ajudar-me amb les correccions de l'anglès.

A la meva mare, la meva germana vull donar-lis un agraïment especial, per la seva ajuda i suport incondicional. El meu darrer agraïment és pel Xavi, pel seu encoratjament continu durant tot aquest temps, pel seu carinyo, per les llargues discussions... i per la seva paciència. A ells tres, i als futurs "projectes" que tenim en comú, vull dedicar-lis aquesta tesis.

Frontcover pictures sources are:

1. UAB-ALARM team
2. UAB-ALARM team
3. Juan Felipe Carrasco
4. www.lanacion.com.ar

Back cover:

1. www.sealinggreen.com
2. www.indymedia.ie
3. Rosa Binimelis
4. UAB-ALARM team
5. Rosa Binimelis